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"CONSERVATION THROUGH EDUCATION"

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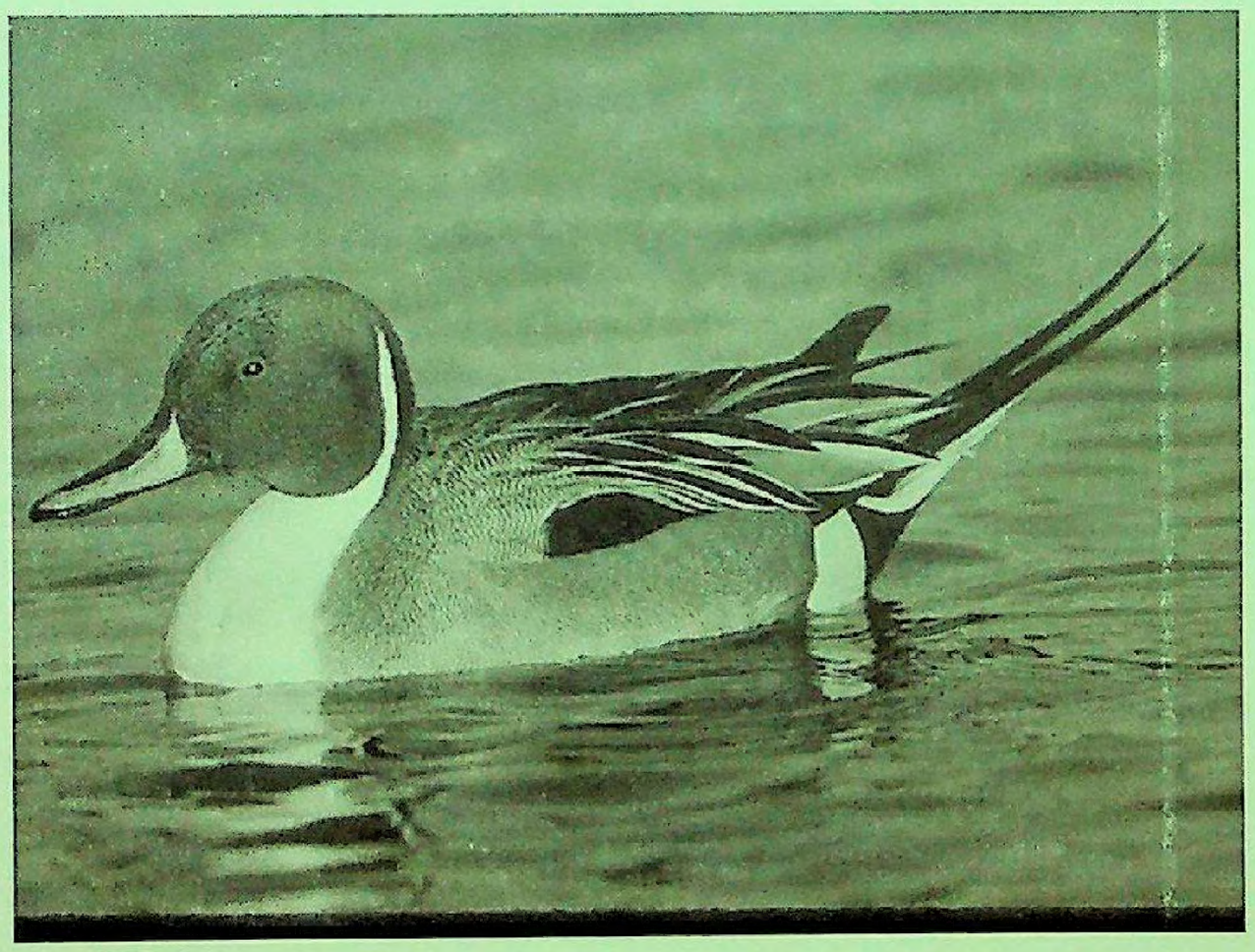

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Please direct correspondence to:

David W. Kohlhorst or James J. Orsi
Co-Editors-in-Chief
California Fish and Game
4001 North Wilson Way
Stockton, California 95205-2486
e-mail: dkohlhor@delta.dfg.ca.gov
jorsi@delta.dfg.ca.gov

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NESTING ECOLOGY OF DUCKS AT EAGLE LAKE, LASSEN COUNTY, CALIFORNIA

RAYMOND J. BOGIATTO
Department of Biological Sciences
California State University
Chico, California 95929-0515

I collected data on duck nesting community composition, nest density, nesting chronology, nest cover, and nest success at Eagle Lake, Lassen County, California from 1990 to 1993. Lesser scaup, *Aythya affinis*, and gadwall, *Anas strepera*, were the most common nesters, constituting 80.3–92.3% of all nests located. Nest densities of lesser scaup ranged from 1.2 to 31.4 nests/ha and nest densities of gadwall ranged from 3.1 to 13.8 nests/ha. Gadwall initiated clutches from 15 April to 15 July, with a peak from 1 to 15 June. Lesser scaup initiated nests from 16 May to 15 August, with a peak from 16 June to 15 July. Stands of nettle, *Urtica holosericea*, and gray rabbitbrush, *Chrysothamnus nauseosus*, were frequently used as upland nest cover by lesser scaup; gadwalls; northern pintails, *Anas acuta*; and mallards, *A. platyrhynchos*, supporting 30.9% and 26.0% of all nests. Hardstem bulrush, *Scirpus acutus*, was the most important shoreline cover plant, supporting 23.3% of all nests. Annual estimates of nest success on islands ranged from 66.7% to 90.0%. On peninsulas, estimated nest success ranged from 6.5% to 38.5%. Predation was the primary cause of nest failure, resulting in nest losses from 0.0% to 18.3% on islands and from 61.5% to 93.5% on peninsulas.

INTRODUCTION

Studies on the nesting ecology of ducks in northeastern California have focused primarily on habitats in the Klamath Basin and at Honey Lake which support large numbers of nesting ducks (Miller and Collins 1954, Rienecker and Anderson 1960, McLandress et al. 1996). Management of duck populations in the Pacific Flyway may benefit from an understanding of smaller, more isolated nesting communities such as that of Eagle Lake, Lassen County, California. Currently, information on the waterfowl nesting community at Eagle Lake is limited to data on common mergansers, *Mergus merganser*, from 2 studies of piscivorous nesters (Gould[1] 1974, Lederer 1976).

The objectives of my study were to 1) describe the nesting community and calculate nest densities for duck species nesting on island and peninsular habitats at Eagle Lake, 2) determine the chronology of clutch initiation for each species, 3) describe vegetation used as nesting cover, and 4) determine the relative success of island and peninsular nests.

[1] Gould, G.I., Jr. 1974. Breeding success of piscivorous birds at Eagle Lake, California. M.S. Thesis, Humboldt State University, Arcata, California, USA.

STUDY AREA

Eagle Lake, the 2nd largest natural freshwater lake in California (approximately 11,000 ha), lies on the Modoc Plateau east of the Cascade Range (40°N, 120°W) (Fig. 1). The lake is bordered by coniferous forests of Jeffrey pine, *Pinus jeffreyi*; incense cedar, *Calocedrus decurrens*; and white fir, *Abies concolor*, to the southeast, south, and west and by steppe habitats dominated by big sage, *Artemesia tridentata*; gray rabbitbrush, *Chrysothamnus nauseosus*; and western juniper, *Juniperus occidentalis*, to the north and east.

Two study sites were selected based on the presence of nesting cover and active duck nests. The Pelican Point site (PP) is an 88-ha peninsula located on the west side of the lake, 3 km south of Spaulding Tract (Fig. 1). The peninsula, made up of basalt and granitic substrata, is characterized by stands of hardstem bulrush, *Scirpus acutus*; gray rabbitbrush; locoweed, *Astragalus lentigenosus*; and nettle, *Urtica holosericea*. In addition to ducks, vegetation patches on PP provide nesting cover for Great Basin Canada geese, *Branta canadensis moffitti*; snowy egrets, *Egretta thula*; black-crowned night-herons, *Nycticorax nycticorax*; and great blue herons, *Ardea herodias*. Also, areas of open basalt at the east end of PP serve as habitat for colonial-nesting California gulls, *Larus californicus*; ring-billed gulls, *L. delawarensis;* and double-crested cormorants, *Phalacrocorax auritus*, during years when PP is insular. Approximately 1.6 ha of nesting cover for ducks is located near the eastern tip of the peninsula, isolated from the mainland by 1.2 km of non-vegetated substrata. In 1990, at the onset of my investigation, PP was isolated from the mainland by 75 m of shallow open water, but was peninsular from 1991 to 1993.

The Miner's Point Island site (MPI) is located 450 m off the east shore of the lake (Fig. 1). This 1.5-ha island is characterized by 0.3 ha of nesting cover composed of nettle interspersed throughout basalt cobble- and boulder-sized substrata, as well as dense stands of hardstem bulrush. The remainder of the island is non-vegetated basalt gravels. In addition to ducks, MPI provides nesting habitat for Great Basin Canada geese; killdeer, *Charadrius vociferus*; spotted sandpipers, *Actitis macularia*; yellow-headed blackbirds, *Xanthocephalus xanthocephalus*; and Forster's terns, *Sterna forsteri*.

METHODS

Field surveys were conducted from mid-April through early September 1990–1993. Sites were surveyed on 1 or 2 successive days every 2 weeks in order to minimize disturbance to nesting females (Lokemoen et al. 1984). All surveys were conducted between 0700 and 1200 hours, when laying or incubating hens are most likely to be at the nest (Miller and Johnson 1978). Nests were located through systematic searches of all patches of woody and herbaceous vegetation with persons spaced 5 m apart. Flushed hens were identified to species and nests were marked with yellow flagging bearing an identification number. Flags were attached to vegetation approximately 5 m from the nest to facilitate relocation.

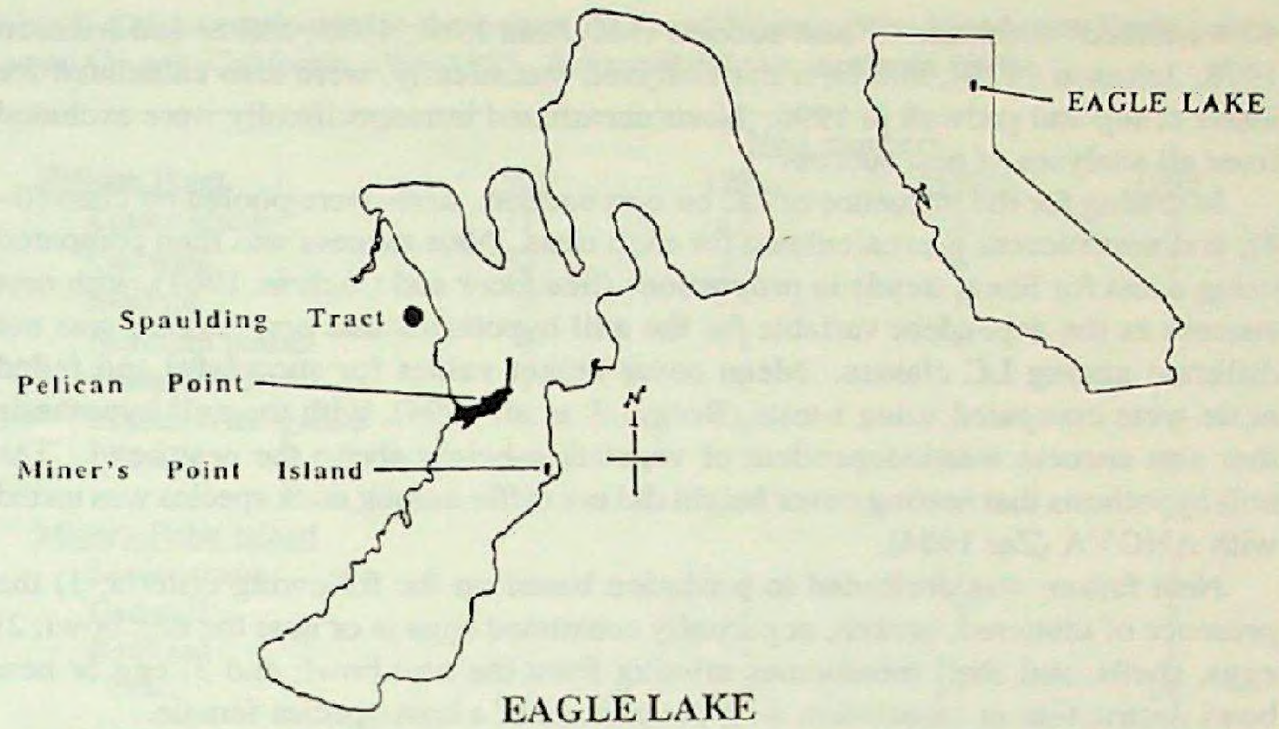

Figure 1. Eagle Lake, Lassen County, California, showing the location of the Pelican Point and Miner's Point Island study sites.

Vegetative cover at nests was identified to species and height of the cover above the nest bowl was recorded to the nearest 0.1 m. Lateral concealment (LC), a measure of nest visibility from each of the 4 cardinal directions, was rated from 0 to 4 (number of sides concealed) for each nest (Hines and Mitchell 1983).

Nest densities were estimated by dividing the largest number of active nests at any time by the area of total available nesting cover. Habitat patches were small and easily measured by hand using a Brunton Compass, flagging, and two 30-m tapes.

Clutch initiation date was estimated using only those nests located during the egg-deposition period and only for those species with ≥ 5 nests. I assumed that hens laid 1 egg per day and that egg deposition had already occurred on the date the nest was first located.

Total clutch size, defined as the maximum number of eggs known to have been deposited, was recorded for each nest. Only 3 host species eggs were measured per nest to minimize disturbance. All eggs deposited by interspecific parasites were identified to species, counted, and measured. All egg measurements were maximum length to the nearest 0.1 mm. Down feathers were then arranged over all eggs to minimize heat loss.

Nest success was estimated as the proportion of nests in which at least 1 egg hatched successfully (Miller and Johnson 1978, Hines and Mitchell 1983). This estimate is referred to as the "Traditional Method" estimate (Klett and Johnson 1982, Bruggink et al. 1994). Traditional estimates for 1992 and 1993 were compared within and between years by habitat using chi-square tests (Zar 1984). The null hypotheses were that 1) nest success was independent of habitat type and 2) the pattern of nest success by habitat did not differ between years. That is, the relationship between habitat type and nest success was consistent from year to year. "Mayfield

40% Method" estimates of nest success (Mayfield 1961, 1975; Miller and Johnson 1978; Johnson 1979), although not analyzed statistically, were also calculated for lesser scaup and gadwall in 1990. Nests parasitized intraspecifically were excluded from all analyses of nest success.

In testing for the influence of LC on nest success, nests were pooled by class (0–4), and nest success was calculated for each class. Nest success was then compared using a test for linear trends in proportions (Snedecor and Cochran 1967), with nest success as the dependent variable for the null hypothesis that nest success was not different among LC classes. Mean cover height values for successful and failed nests were compared using t-tests (Bruggink et al. 1994), with the null hypothesis that nest success was independent of vegetation height above the nest bowl. The null hypothesis that nesting cover height did not differ among duck species was tested with ANOVA (Zar 1984).

Nest failure was attributed to predation based on the following criteria: 1) the presence of scattered, broken, or partially consumed eggs in or near the nest bowl; 2) eggs, shells, and shell membranes missing from the nest bowl; and 3) egg or nest bowl destruction in association with the carcass of a host-species female.

Interspecific parasitism was identified based on the presence of eggs of different colors, shapes, and sizes in a single nest. Intraspecific nest parasitism is often difficult to identify due to the similarity in egg morphology. Host species eggs deposited into the nest bowl following the onset of incubation, as well as clutch sizes exceeding published ranges (Bellrose 1980, Ehrlich et al. 1988) by $\geq$1 egg were attributed to intraspecific parasites.

RESULTS AND DISCUSSION

Nesting Community

Lesser scaup, *Aythya affinis*, and gadwall, *Anas strepera*, were the most abundant nesting ducks in sampled habitats at Eagle Lake during my study (Table 1). Nests of these species made up 80.3–92.3% of all nests located between 1990 and 1993. Mallards, *Anas platyrhynchos;* northern pintails, *Anas acuta*; cinnamon teal, *Anas cyanoptera;* redhead, *Aythya americana;* and common merganser also nested at Eagle Lake in lower numbers.

Several authors (Duebbert 1966, 1982; Duncan 1986; Hines and Mitchell 1983; Lokemoen et al. 1984; Miller and Collins 1954; Vermeer 1968, 1970) have discussed the relative importance of islands and isolated peninsulas to gadwall, mallards, and lesser scaup, because these habitats provide protection against mammalian predators. As all nests located during this study were either on islands or isolated peninsulas, it was not surprising to find these species making up the bulk of the terrestrial nesting community at Eagle Lake.

Nest Densities

Densities of simultaneously active lesser scaup nests at PP from 1990 to 1993 were 19.4, 8.1, 1.9, and 1.3 nests/ha of nesting vegetation. Gadwall nest densities at

Table 1. Duck nests located at the Pelican Point and Miner's Point Island sites, Eagle Lake, Lassen County, California, 1990-1993. Pelican Point was insular in 1990.

	Nest numbers			
Pelican Point	1990	1991	1992	1993
Lesser scaup	31	13	3	2
Gadwall	22	17	8	5
Mallard	6		1	
Northern pintail	6	1	1	
Cinnamon teal	1	1	-	-
Common merganser	-	1	-	1
Total	66	33	13	8
Miner's Point Island				
Lesser scaup	-	-	11	8
Gadwall	-	-	2	2
Redhead	-	-	-	1
Total	-	-	13	11
Grand total	66	33	26	19

PP for the same period were 13.8, 10.6, 5.0, and 3.1 nests/ha. At MPI, lesser scaup nest densities were 31.4 and 22.9 nests/ha in 1992 and 1993. Gadwall nest density at this site was 5.7 nests/ha in both 1992 and 1993. Nest densities were not estimated for other, less-common nesting species.

Results from several studies conducted throughout the Prairie Pothole Region of North America (PPR) suggest that nest density values for ducks tend to be higher on islands (Duebbert 1982, Hines and Mitchell 1983, Duncan 1986, Vermeer 1970). Density figures for lesser scaup and gadwall at Eagle Lake illustrate the importance of island habitats to these species in northeastern California. However, densities of gadwall on MPI were low in 1992 and 1993 (5.7 nests/ha), probably as a result of poor cover conditions.

With the exception of several sparse stands of nettle, the only dense nesting cover on MPI occurred along the shoreline as stands of hardstem bulrush. Results suggest that dense stands of rabbitbrush and nettle, which did not occur on MPI during this study, are the most frequently used cover types by nesting gadwall at Eagle Lake (Table 2).

Clutch Initiation and Size

Clutch initiation data from Eagle Lake (Fig. 2) are consistent with results from other studies in northeastern California (Miller and Collins 1954, Rienecker and Anderson 1960) and the PPR (Duebbert 1966, Klett et al. 1988, Lokemoen et al. 1984, Vermeer 1970), with northern pintail nesting first and gadwall and lesser scaup nesting last. The 1 August clutch initiation for scaup at MPI in 1993 was likely a renesting effort, based on the date, as well as a clutch size (6 eggs), which are consistent

Table 2. Vegetation used as nest cover by ducks on Pelican Point and Miner's Point Island, Eagle Lake, Lassen County, California, 1990-1993.

	Nest cover type											
	Rabbitbrush		Nettle		Locoweed		Bulrush		Other[c]		Total	
Nesting species	No.[a,b]	%	No.	%	No.	%	No.	%	No.	%	No.	%
Lesser scaup	12	17.6	13.5	19.8	8	11.8	24	35.3	10.5	15.5	68	100
Gadwall	19.5	34.8	25	44.7	2.5	4.5	4.5	8	4.5	8	56	100
Northern pintail	5	62.5	1	12.5			2	25			8	100
Mallard	1	14.3	5	71.4	1	14.3					7	100
Cinnamon teal					1	50			1	50	2	100
Common merganser							2	100			2	100
Redhead							1	100			1	100
Total	37.5	26.0	44.5	30.9	12.5	8.7	33.5	23.3	16.0	11.1	144	100

[a] Number of nests with designated cover type.

[b] For those nests constructed beneath 2 cover types, a value of 0.5 nests was recorded for each cover type.

[c] Includes dock, *Rumex angiocarpus*; rush, *Juncus balticus*; sedge, *Carex* sp.; Russian thistle, *Salsola kali*; cheatgrass, *Bromus tectorum*; saltgrass, *Distichlis spicata*; basalt boulder; and non-active heron and egret nests.

with data for renesting scaup (Hunt and Anderson 1966). In addition, 2 cinnamon teal clutches were initiated during the period of 16 May–15 June and 1 clutch each of common merganser and redhead was initiated prior to 1 June.

As a result of small samples for other species, only mean clutch sizes for gadwall and lesser scaup were compared with results from other studies. Gadwall mean clutch size of 9.3 eggs (range = 7–13, SE = 0.28, n = 32) at Eagle Lake is similar to values observed in North Dakota (Duebbert 1966), although somewhat smaller than reported for Tule Lake (11.0 eggs) (Miller and Collins 1954) and Lower Klamath refuges (11.0 eggs) (Rienecker and Anderson 1960) or the 10.4 eggs reported for several studies by Bellrose (1976). Similarly, clutch size for lesser scaup at Eagle Lake (mean = 9.7, range = 7–14, SE = 0.29, n = 44), although within published ranges, was somewhat lower than values at Tule Lake (10.7 eggs) (Miller and Collins 1954) and Lower Klamath (10.7-11.0 eggs) (Rienecker and Anderson 1960) refuges. The elimination of nests suspected of having incurred intraspecific parasitism could account for the lower values at Eagle Lake.

Nesting Cover

Stands of nettle and gray rabbitbrush were frequently used as nest cover in upland areas of PP by lesser scaup, gadwall, northern pintail, and mallard. Small patches of nettle served as the only upland plant species on MPI used by nesting ducks in 1992 and 1993. In all, 17.6% of lesser scaup nests and 34.8% of gadwall nests were constructed beneath stands of rabbitbrush (Table 2). Nettle served as a cover plant for 19.8% of lesser scaup nests and 44.7% of gadwall nests during this study. Other

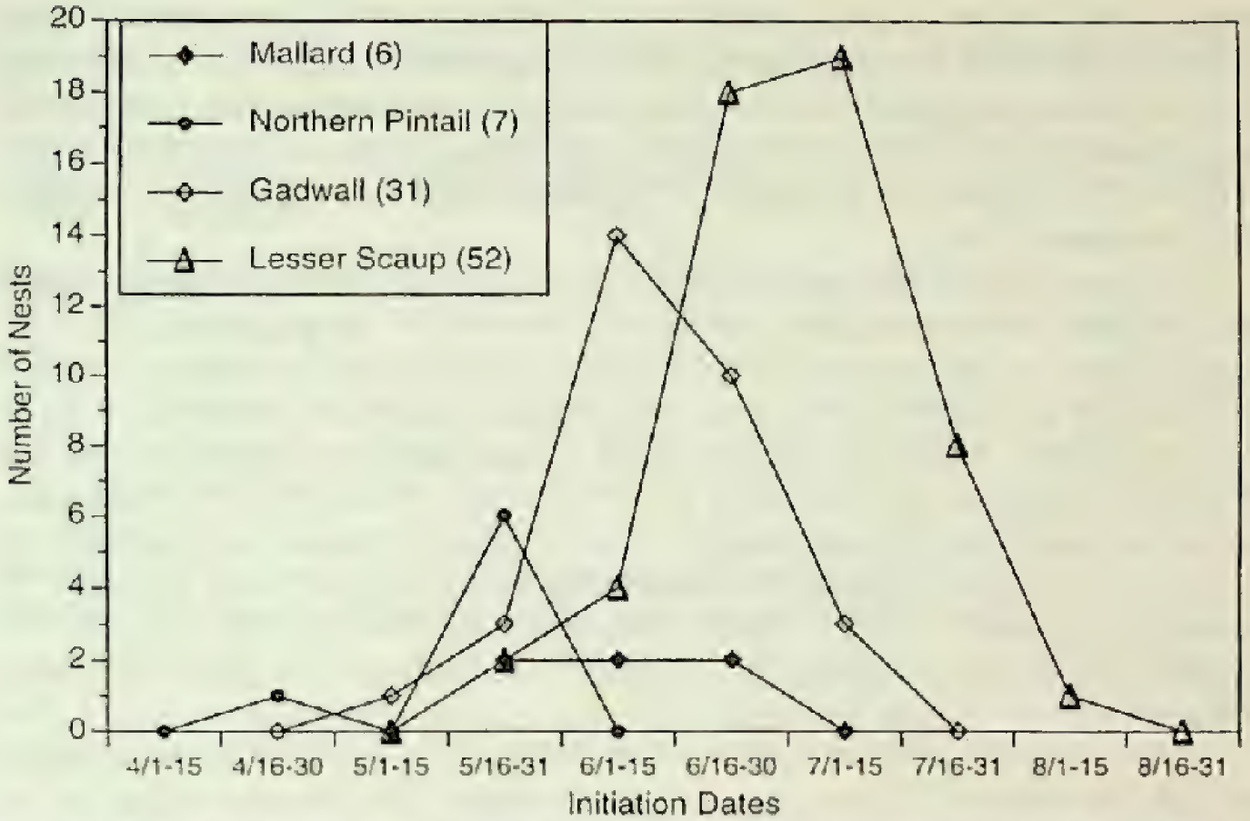

Figure 2. Nest initiation dates for common duck species at Eagle Lake, Lassen County, California, 1990–1993.

upland species such as locoweed and dock, as well as non-active heron and egret (Ardeidae) nest structures also served as upland nest cover for ducks at PP.

Stands of decadent (residual stubble) and new growth hardstem bulrush served as the most important shoreline nesting cover for ducks at both PP and MPI, supporting 23.3% of all nests located. In total, 35.3% of lesser scaup (n = 68), both common merganser, and 1 redhead nests were constructed in hardstem bulrush stands, but gadwall and northern pintail used these habitats sparingly (Table 3).

Dense stands of rabbitbrush, nettle, bulrush, and locoweed were used most frequently by ducks nesting at my study sites (Table 2). Although the species composition among habitats may vary, the literature from northeastern California (Miller and Collins 1954, Rienecker and Anderson 1960) and the PPR (Duebbert 1966, Hines and Mitchell 1983, Lokemoen et al. 1984, Duncan 1986) are consistent in stating the relative importance of dense stands of shrubs and upright forbs to nesting ducks. Although not designed to address issues of nest site selection and habitat preference, data from my study suggest a preference for dense stands of nesting cover. This generalization is based largely on the presence of relatively unused cover types such as saltgrass, *Distichlis spicata*; sedge, *Carex* spp.; rush, *Juncus* sp.; and heliotrope, *Heliotropium curassavicum*.

Nest Success

Nest success varied widely between nesting locations and among years (Table 3). Traditional Method estimates of nest success for gadwall ranged from 50.0%

(1992) to 100.0% (1993) on islands and from 0.0% (1991, 1993) to 50.0% (1992) on peninsulas (Table 3). The Mayfield estimate for gadwall nesting on PP in 1990 was 34.3%. Traditional Method nest success estimates for island-nesting lesser scaup ranged from 65.4% (1990) to 90.0% (1992); nesting success ranged from 0.0% (1991, 1993) to 33.3% (1992) on peninsulas. The Mayfield estimate for scaup nesting on PP in 1990 was 34.0%.

Traditional Method nest success estimates for all duck species by habitat ranged from 66.7% to 90.0% on islands and from 6.5% to 38.5% on peninsulas (Table 4). The difference in nest success between habitats (islands and peninsulas) was not significant ($\chi^2 = 2.0$, df = 1, $P > 0.1$) in 1992, but was significant in 1993 ($\chi^2 = 10.77$, df = 1, $P < 0.005$). Differences in the pattern of nest success by habitat in 1992 and 1993 were significant ($\chi^2 = 6.30$, df = 1, $P < 0.025$). This pattern of higher nest success on islands than on peninsulas is consistent with other studies from northeastern California (Miller and Collins 1954, Rienecker and Anderson 1960) and the PPR (Keith 1961, Duebbert 1966, Vermeer 1968, Hines and Mitchell 1983, Lokemoen et al. 1984), which have illustrated the importance of carnivore-free islands to nesting ducks.

Studies from the PPR (Cowardin et al. 1985, Klett et al. 1988) suggest that Mayfield estimates of 15% nest success for mallards and 20% for late-nesting species such as lesser scaup and gadwall are necessary to sustain a population, assuming normal levels of duckling mortality, hen survival, and philopatry. Although Traditional Method estimates tend to be biased high, evidence suggests that estimates for small, easily searched habitat patches such as those at Eagle Lake tend to be much more accurate (Lokemoen et al. 1984). Thus, while acknowledging that Traditional Method estimates for Eagle Lake (Tables 3 and 4) are likely to be somewhat high, data from my study suggest that vegetated island habitats are necessary for nesting populations of ducks to sustain themselves through time.

Predators were the primary cause of nest failure for ducks nesting on the island and peninsula at Eagle Lake, resulting in the loss of 13 (15.9%) island nests and 44 (84.6%) peninsular nests. These data are consistent with other studies in similar habitats in the PPR (Duebbert 1966, Vermeer 1970, Duebbert 1982, Lokemoen et al. 1984). Evidence of predation in my study included eggs missing from clutches (n = 10 nests), eggs with 1–2-cm-diameter holes (n = 5 nests), egg shells broken and scattered along with nest materials (n = 40 nests), and 1 dead and partially consumed hen gadwall in the nest bowl.

No acts of predation on ducks or duck nests were observed at either sampling location, but raccoon, *Procyon lotor*, and coyote, *Canis latrans*, tracks were common at PP from 1991 to 1993. In addition, 1 adult coyote was sighted on PP during a survey in 1991. Egg shell and nest bowl characteristics at failed nests sites on PP, as well as the condition of 2 female scaup carcasses suggest some predation by both species (Reardon 1951). Also, characteristic signs of striped skunk, *Mephitis mephitis*, and gray fox, *Urocyon cinereoargenteus*, predation (Reardon 1951) were noted at PP.

Evidence of predation at failed nests on PP in 1990, when gull colonies were active, were consistent with predation by gulls which may have resulted in the failure

Table 3. Traditional Method estimates of nest success through hatch for island- and peninsular-nesting gadwall and lesser scaup at Eagle Lake, Lassen County, California, 1990–1993.

		Island		Peninsula	
Year	Species	Total nests	Nest success (%)	Total nests	Nest success (%)
1990	Gadwall[a]	21	71.4		
	Lesser scaup[b]	26	65.4		
1991	Gadwall			16	0.0
	Lesser scaup			12	0.0
1992	Gadwall	2	50.0	8	50.0
	Lesser scaup	10	90.0	3	33.3
1993	Gadwall	2	100.0	5	0.0
	Lesser scaup	7	85.7	2	0.0

[a] Mayfield 40% estimate of nest success for gadwall in 1990 is 34.3%
[b] Mayfield 40% estimate of nest success for lesser scaup in 1990 is 34.0%

Table 4. Traditional Method estimates of nest success through hatch of ducks in island and peninsular habitats at Eagle Lake, Lassen County, California, 1990–1993.

Year	Island habitats (%)	Peninsular habitats (%)
1990	73.3	
1991		6.5
1992[a]	66.7	38.5
1993[b]	90.0	12.5
$\bar{X}\pm$SE	76.7±6.9	19.2±9.8

[a] 1992 nest success figures for island and peninsula sites were not significantly different ($\chi^2 = 2.0$, df = 1, $P > 0.1$).
[b] 1993 nest success figures for island and peninsula sites were significantly different ($\chi^2 = 10.77$, df = 1, $P < 0.005$).

of up to 18.3% of those nests monitored. While some researchers have suggested that waterfowl nesting in association with colonial-nesting gulls may incur heavy predation unless their nests are well concealed (Odin 1957), others have found that nesting ducks may benefit from an association with larid colonies, which may be effective in driving off predatory gulls and crows (Keith 1961, Vermeer 1968).

Nest failure resulting from abandonment ranged from 8.3% (1990) to 16.7% (1992) on islands, but no nest abandonment was observed on peninsulas. Of the 8 abandoned island nests, 3 incurred nest parasitism; reasons for the other 5 desertions are unclear. Potential factors influencing abandonment include human disturbance and predation by raptors on attending females (Greenwood et al. 1995, Keith 1961). In support of the predation hypothesis, osteological remains of lesser scaup and other medium-sized ducks have been identified by the author and others in pellets regurgitated during spring and summer by great horned owls, *Bubo virginianus*, at Eagle Lake (unpublished observations). In addition, 1 gadwall nest parasitized interspecifically

by lesser scaup and 2 scaup nests parasitized intraspecifically were also abandoned. Frequent disturbance by nest parasites has been shown to precipitate nest desertion in ducks (Joyner 1983, Weller 1959). Low abandonment rates for Eagle Lake are consistent with those from studies in northeastern California (Miller and Collins 1954, Rienecker and Anderson 1960) and the PPR (Duebbert 1966, Duebbert 1982).

Nest Concealment and Cover Height

Nest success for LC classes on the peninsula were significantly different ($Z = -2.54$, $df = 62$, $P < 0.05$); success was 11.1% for nests with 0–2 sides concealed and 16.7% for nests with 3–4 sides concealed. No association between LC and nest success existed on islands, where success was similar for nests with 0–2 sides (82.4%) and 3–4 sides (72.6%) concealed ($Z = 0.58$, $df = 88$, $P > 0.05$). These results conflict with studies by Odin (1957) and Hines and Mitchell (1983) that found nest success was positively correlated with LC on islands in Utah and Saskatchewan. The absence of colonial nesting gulls on MPI in 1992 and 1993 may account for these inconsistencies, as the only island nests subjected to gull predation were on PP in 1990.

Although it has been suggested that a positive correlation often exists between cover height above the nest bowl and nest success in ducks (Heiser[2] 1971, Dwernychuk and Boag 1972, Hines and Mitchell 1983), nest cover height on islands ($t = 0.093$, $df = 88$, $P > 0.90$) and peninsulas ($t = 0.825$, $df = 52$, $P > 0.40$) was not significantly different for successful and failed nests at Eagle Lake (Table 5). The relative absence of predatory gulls at both study sites could explain the lack of any significant correlation between cover height and duck nesting success at Eagle Lake. Also, cover height selected by nesting lesser scaup, gadwall, and northern pintail did not differ significantly (Table 6).

Nest Parasitism

Lesser scaup and gadwall served as hosts for both inter and intraspecific nest parasites at Eagle Lake. Parasitic species included lesser scaup, redhead, and gadwall.

Table 5. Mean vegetation height (m) over duck nests on island and peninsular habitats at Eagle Lake, Lassen County, California, 1990–1993. Sample sizes are in parentheses.

Nest fate	Island[a]	Peninsula[b]
Successful nests	0.87 (67)	0.68 (8)
Failed nests	0.89 (23)	0.78 (46)

[a] Difference in mean vegetation height above successful and failed nests on island habitats at Eagle Lake was not significant ($t = 0.093$, $df = 88$, $P > 0.9$).

[b] Difference in mean vegetation height above successful and failed nests on peninsular habitats at Eagle Lake was not significant ($t = 0.825$, $df = 52$, $P > 0.4$).

[2] Heiser, N.G. 1971. Nest site selection of blue-winged teal (*Anas discors*) in northwest Iowa. M.S. Thesis, Iowa State University, Ames, Iowa, USA.

Table 6. Vegetation height (m) over duck nests at Eagle Lake, Lassen County, California, 1990–1993.

Species	Number of nests	Range	Mean	SE
Lesser scaup	68	0.2 - 1.6	0.83	0.05
Gadwall	56	0.1 - 1.8	0.81	0.05
Northern pintail	8	0.4 - 1.4	0.88	0.14

In all, 12 of 50 lesser scaup nests (24%) and 4 of 26 gadwall nests (15.4%) were parasitized on islands, whereas 1 of 16 lesser scaup nests (6.3%) and 2 of 32 gadwall nests (6.3%) incurred parasitism on peninsulas.

Nest parasitism by lesser scaup, redheads, and gadwall has been well documented in the literature (Miller and Collins 1954, Weller 1959, Rienecker and Anderson 1960, Joyner 1983). Data from Eagle Lake suggest a higher frequency of parasitic events on islands. These findings are similar to those of Weller (1959) and Joyner (1983).

MANAGEMENT IMPLICATIONS

Findings from this study are consistent with other North American studies that have estimated the relative importance of islands and isolated peninsulas to nesting ducks (Duebbert 1962, Vermeer 1970, Hines and Mitchell 1983, Duncan 1986). As a result of dramatic annual shifts in lake levels, these habitat types are often limited at Eagle Lake, thereby increasing the importance of each. Hence, watershed and wildlife managers should be aware of 2 potential threats to these habitats and their nesting communities, namely human and livestock intrusion. Eagle Lake, with its trophy rainbow trout, *Oncorhynchus mykiss aquilarum*, fishery, receives an enormous amount of recreational use by shore and boat anglers. Also, cattle grazing, a common practice on U.S. Forest Service, Bureau of Land Management, and private parcels along the shores of the lake, can have a devastating effect on nest cover. Cattle encroachment onto PP in 1991 resulted in the complete removal of all locoweed stands used in 1990 by nesting lesser scaup and gadwall. A fence constructed across the base of PP by the Forest Service prior to the 1992 nesting season was effective at excluding cattle from the peninsula thereafter.

Management recommendations should include: 1) posting of signs asking that recreationists avoid critical nesting habitats from March through mid-September, 2) posting and distribution of interpretive information on local wildlife and wildlife habitats at marinas and campgrounds, and 3) construction of fences by land owners and administrators to prevent intrusion of domestic livestock into patches of critical avian nesting habitats.

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CALIFORNIA WILDLIFE HABITAT RELATIONSHIPS SYSTEM: A TEST IN COASTAL SCRUB AND ANNUAL GRASSLAND HABITATS

JUDD A. HOWELL
U.S. Geological Survey
Biological Resources Division
Western Ecological Research Center - Golden Gate Field Station
Fort Cronkhite, Building 1063
Sausalito, California 94965

REGINALD H. BARRETT
Department of Environmental Science, Policy, and Management
145 Mulford Hall
University of California
Berkeley, California 94720

We tested predictions of the California Wildlife Habitat Relationships (CWHR) System in coastal scrub and annual grassland. We detected a total of 28 species of terrestrial vertebrates: 18 mammals, 9 reptiles, and 1 amphibian. The CWHR System prediction omitted 4 of these species: 3 domestic mammals and 1 reptile. For the 2 habitats combined, CWHR predicted a total of 38 species: 23 mammals, 13 reptiles, and 2 amphibians. We detected 64% of these predicted grassland species and 71% of predicted coastal scrub species. For the habitats combined, we detected 65% of the species predicted to be present by the CWHR System. We detected 68% of the mammals, 62% of the reptiles, and 50% of the amphibians predicted for these habitats. The CWHR System theoretically predicts absence rather than presence, since it is assumed that all 288 regularly occurring mammals, reptiles, and amphibians occur anywhere unless one can argue that a specific habitat, location, or habitat element is not available. By including predictions of species absence in the assessment of model performance, observed accuracy of the CWHR model predictions increased to 96% for both habitats.

INTRODUCTION

Wildlife biologists have developed habitat models to predict animal species composition in selected locales and the relative ability of habitats to support wildlife populations (Verner et al. 1986, Morrison et al. 1992, Patton 1992). Several approaches have been used to model relationships of animals to their habitats at the community level (Thomas[1] 1979, USFWS[2] 1981, Nelson and Salwasser 1982).

[1] Thomas, J.W. 1979. Wildlife habitats in managed forests, the Blue Mountains of Oregon and Washington. U.S. Department of Agriculture, Forest Service, Agriculture Handbook No.553, Washington, D.C., USA.

[2] USFWS (U.S. Fish and Wildlife Service). 1981. Standards for the development of habitat suitability index models. U.S. Department Interior, Fish and Wildlife Service, Division of Ecological Services, 103-ESM. U.S. Government Printing Office, Washington, D.C., USA.

Since 1981, wildlife biologists from over 20 federal and state agencies in California have met quarterly as the California Interagency Wildlife Task Group (CIWTG). The CIWTG proposed and directed development of the California Wildlife Habitat Relationship (CWHR) System. Information for the System was derived from literature searches and expert opinions. Products include a System Guide (Airola[3] 1988); habitat descriptions (Mayer and Laudenslayer 1988); species notes and range maps for amphibians, reptiles, birds, and mammals (Zeiner et al. 1988, 1990a, 1990b); and a computer data base (Timossi and Dedon 1987) with information on 647 vertebrate species that regularly occur in the state. The database includes qualitative models for all species that rate the value of each seral stage of a habitat for reproduction, cover, and food as (i) low, (ii) medium, (iii) high, or (iv) no value. Users can focus the output from the System by specifying habitat elements, such as snags, important to individual species. Users may include or exclude 123 habitat elements in a database query. Fifty-two terrestrial and aquatic habitats are described by dominant vegetation, subdivided by structure and stand age, and cross-referenced with 9 other vegetation classification systems for California (deBecker and Sweet 1988). A species composition request for a habitat involves (i) defining the location, such as county, national forest, or California Department of Fish and Game Region; (ii) determining habitat elements to include or exclude; and (iii) reviewing thoroughly the species notes to determine ranges and other factors influencing the distribution of the species.

The CWHR predictions of vertebrate community composition and relative habitat values are based on untested models. Models for 11 of the 52 habitat types in the CWHR have received preliminary field testing (Garrison[4] 1993). Early validation of CWHR models tended to focus on birds (Garrison[4] 1993), although Raphael and Marcot (1986) included mammals and herpetofauna in their CWHR validation study, as did Block et al. (1994) in later work.

Although the validation process is slow and often overlooked, validated CWHR models are of great value because direct inventory of wildlife is costly. The objectives of our pilot study were to test the CWHR models for mammals, reptiles, and amphibians in annual grassland and coastal scrub habitats and to evaluate the application of some wildlife inventory methods for monitoring biodiversity at Golden Gate National Recreation Area (GGNRA), California.

STUDY AREA

The 1,427-ha study area is located in the Marin Headlands in the North District of GGNRA and encompasses the 3 principal watersheds of the district: Rodeo, Gerbode, and Tennessee valleys. Each watershed rises from sea level to about 305 m.

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[3] Airola, D.A. 1988. Guide to the California Wildlife Habitat Relationships System. California Resources Agency, Department of Fish and Game, Sacramento, California, USA.

[4] Garrison, B.A. 1993. Validation studies of the CaliforniaWildlife Habitat Relationships System. Fish and Wildlife Information Exchange Newsletter 2:2-5.

Soils are derived from a complex of radiolarian chert, basalt, and sandstones of the Franciscan Formation (SWA Group[5] 1975). Vegetation is a mosaic of coastal scrub, consisting of coyote brush, *Baccharis pilularis* var. *consanguinea*; coastal sage, *Artemisia californica*; bush lupine, *Lupinus arboreus*; bush monkeyflower, *Mimulus aurantiacus*; poison oak, *Toxicodendron diversiloba*; and a mixture of annual and perennial grasses (Barbour and Major 1988). Small patches of oak, *Quercus agrifolia, Q. wislizeni,* and *Q. kelloggii* and the chaparral species *Ceanothus thyrisflorus* and *Adenostoma fasciculatum* are found at a few sites (Howell 1970). Riparian areas are characterized by willow, *Salix coulteri* and *S. lasiolipis,* and introduced eucalyptus, *Eucalyptus globulus* (Howell 1970).

The climate of the area is Mediterranean, locally modified by summer fog. Precipitation averages 686 mm from November to April. The summer drought is softened by coastal fog drip typical of forested north coastal California (SWA Group[5] 1975). The closest weather station is at Muir Woods National Monument 6 km north of the study site.

METHODS

Sample Plot Selection

Grassland and coastal scrub habitats were mapped using LANDSAT TM data (25 October 1984, Quarter Scene 1, Scene No. 5023818160) (Howell[6] 1993). Results were incorporated into a geographic information system with GRASS software (Westervelt et al. 1986). Four hundred potential sample points were randomly selected from among pixel centers of the classified cover map. Two hundred points were identified in each habitat. The Universal Transverse Mercator (UTM) coordinates were plotted on an enlarged U.S. Geological Survey topographic map with a scale of approximately 1:20,000. Each point was located in the field by 2–4 people using meter tapes, calibrated range finders, and hand-held compasses. Starting points were located by identifying features from the topographic map, such as road and trail junctions. The location of the center stake for each study plot corresponded to the computer-generated UTM coordinate for that point. Because of the magnitude of the project, it was only possible to establish 100 plots in each habitat type. In spring 1991, a licensed surveyor surveyed the locations of plot centers to a tolerance of 3 cm UTM and 30 cm elevation.

At each randomly selected point a steel stake was driven into the ground to form the center of the 10-m radius plot. The dimensions of the plot were designed to fit within a single pixel (Fig. 1). Each plot was permanently identified with a serially numbered aluminum tag. Vegetation was sampled at each plot along four 25-m

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[5] SWA Group. 1975. Preliminary information base, Golden Gate National Recreation Area/North. National Park Service, San Francisco, California, USA.

[6] Howell, J.A. 1993. Wildlife habitat inventory and monitoring, Golden Gate National Recreation Area, California. Ph.D. Dissertation, University of California, Berkeley, California, USA.

transects by point- or foliar-intercept sampling methods (Howell[6] 1993). Vegetation transects were spaced at 5-m intervals.

Wildlife Distribution and Occurrence

Systematic Detection Techniques

During July and August 1990, 143 randomly selected study plots were sampled in grassland and coastal scrub for mammals, reptiles, and amphibians. During July and August 1991, 110 plots were sampled, 52 of which were randomly selected from the 1990 sample for re-sampling to examine between-year variation. It took the 2-year interval to sample a total of 201 plots. Approximately 30 plots were sampled simultaneously for each of four 10-day intervals. Sampling intervals corresponded with the arrival of an Earthwatch team of 10 volunteers.

Study teams were composed of a team leader, a biological technician in botany or wildlife, and 2 or 3 Earthwatch volunteers who participated in all phases of sampling. At the end of each sampling day, data were entered into a computer database by the Earthwatch volunteers, reviewed by the biological technician, and edited by the authors.

Species were identified using standard field guides (Stebbins 1985, Jameson and Peeters 1988) and reference specimens obtained from the California Academy of Sciences.

The CWHR test data from the 2 sample years were pooled by summing the number of individuals at a site from each year's data set. This approach overestimated the

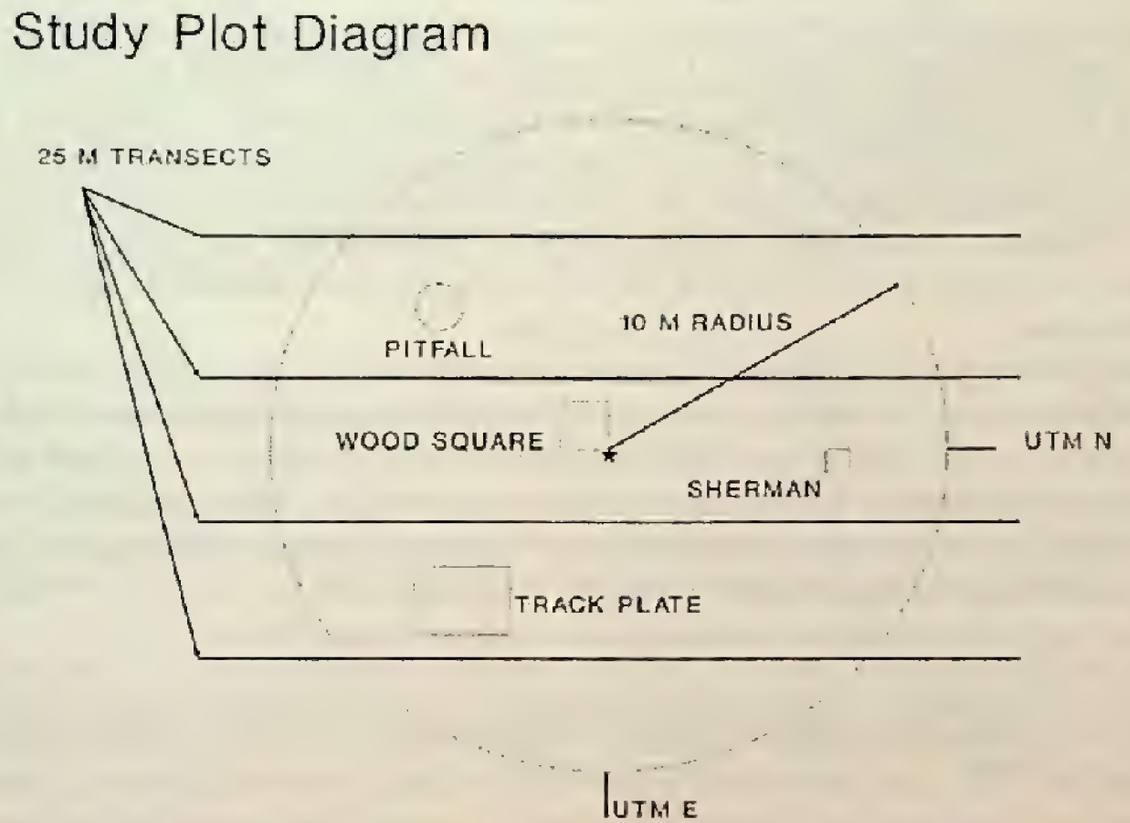

Figure 1. Schematic diagram of study plot for sampling vegetation and wildlife.

actual number of individuals at a plot but emphasized persistent use of a plot. To determine the validity of pooling the 2 annual data sets, between-year variation of species detections was examined using chi-square (Lehmann 1975; Norusis 1988a, 1988b).

Mammals – Small mammals were sampled by placing one 8- x 9- x 22-cm Sherman live trap (H.J. Spencer & Sons, P.O. Box 131, Gainsville, Florida 32602[7]), baited with peanut butter and rolled oats, 5 m from each center stake (Davis 1982). Traps were checked daily, re-baited if necessary, and small mammals captured were recorded and marked with metal ear tags (size 1005-1, National Band and Tag Co., P.O. Box 430, Newport, Kentucky 41072[7]) for later identification. Abundance was determined by considering only captures of newly tagged individuals rather than including recaptures.

Carnivorous mammals were sampled using sooted track plates (Barrett 1983, Taylor and Raphael 1988) baited with punctured cat food cans. When cans disappeared, they were replaced with new ones. Track stations (two 40- x 80-cm aluminum sheets placed to form an 80- x 80-cm square) were set out at a 120° angle from the pitfall (see following section) and Sherman traps (Fig. 1), checked daily, and recovered at the end of the period. Old tracks were circled with a line scratched in the soot to prevent confusion with new tracks. Track plates frequently showed low repeat use, particularly for skunks, raccoons, gray fox, and bobcat. For these species tracks were considered to have been made by new individuals each day.

Reptiles and amphibians – Herpetofauna was sampled with pitfall traps and cover boards. One pitfall trap, consisting of a 20-liter bucket placed in the ground and covered by a 30- x 30- x 0.7-cm plywood lid raised 5 cm above the rim (Davis 1982, Bury and Raphael 1983), was placed 5 m from the center stake of each plot, on the same contour as the stake, and at a 120° angle from the Sherman trap and track plate (Fig. 1). Pitfalls were lined with leaf litter to prevent desiccation of amphibians and cotton to prevent hypothermia in small mammals. Buckets not in use were covered with lids, which were then covered with soil and a large rock. Pitfalls were checked daily. Captured reptiles and amphibians were recorded but not marked. Small mammals captured in pitfall traps were treated in the same manner as those from Sherman traps.

Extra plywood pitfall lids were used as cover boards and placed near each plot center stake to provide artificial cover to detect reptiles and amphibians (DeGraff and Yamasaki 1992, Grant et al. 1992). During 1990, the lids were placed at the beginning of the 10-day sampling period and checked daily. Detections were very low in 1990 ($n = 4$), possibly because of daily disturbance. Hence, during 1991, the cover boards were checked only at the end of the period.

Detections of reptiles on the track plates also were recorded.

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[7] Reference to trade names does not imply an endorsement by the California Department of Fish and Game.

Incidental Observations

Incidental wildlife observations were recorded as the study teams walked to and from the plots, following the same paths each day. Although the systematic methods reported above are preferred, ignoring species observed on the way to and from the study plots (but not detected in the systematic survey) would underestimate the number of species present.

CWHR Validation

Vertebrate community composition was predicted by searching the CWHR database for all seral stages of coastal scrub and annual grassland in Marin County (Version 09-10-89) (Timossi and Dedon 1987). No habitat elements were used to include or exclude species, thereby generating the most comprehensive species lists. Species that the model identified as not reproducing in the habitat were excluded to provide a focused list of species that needed the habitat to persist in the landscape. The broad list of species increased the commission error by listing species that were not found, but reduced omission error, reducing the risk of missing species that were present. The CWHR predictions were compared with field data from this study and an unpublished terrestrial vertebrate list developed for GGNRA (White[8] 1974). Omission errors occurred when species were observed during sampling but were not predicted by the CWHR. Commission errors occurred when species were not observed during sampling but were predicted by CWHR. Omission and commission errors were determined for each habitat type and accuracy was assessed (Cohen 1960, Congalton et al. 1983).

The above conventional test of the CWHR model may not accurately reflect how well the model works. As the CWHR model theoretically predicts absence rather than presence, we also tested model performance using Cohen's Kappa ($\hat{k}$) to measure the reduction of error in the confusion matrix (Cohen 1960). This method has been used for assessing image classification accuracy by determining how well a model performs compared to chance alone (Congalton et al. 1983).

RESULTS

Systematic sampling in the GGNRA was conducted on 143 plots for 5,543 trap nights in 1990 and on 110 plots for 3,446 trap nights in 1991.

Pooling data for the 2 years was considered to be valid as only 2 taxa showed significant variation between years: striped skunk, *Mephitis mephitis*, detections on track plates ($\chi^2 = 12.1$, df = 4, $P = 0.016$) and snake detections on track plates ($\chi^2 = 9.8$,

[8] White, M. 1974. A provisional list of the wildlife of the Golden Gate National Recreation Area, with recommendations for management and research. Unpublished manuscript. Pages 153-172 *in:* J.A. Howell. 1982. Natural resources management plan and environmental assessment, Golden Gate National Recreation Area, U.S. Department of the Interior, National Park Service, Golden Gate National Recreation Area, San Francisco, California, USA.

df = 2, $P = 0.007$). More striped skunks were detected in 1990 and more snakes were detected in 1991.

A total of 28 species of terrestrial vertebrates, excluding birds, was detected in the systematic and incidental surveys combined: 18 mammals, 9 reptiles, and 1 amphibian (Table 1). Fourteen mammals and 4 reptiles were detected in the systematic survey and 4 mammals, 5 reptiles, and 1 amphibian were incidentally observed. The CWHR System omitted 4 species (3 were domestic mammals) detected in our sampling (Table 1) and predicted the presence of 3 species that were not on the GGNRA's species list: coachwhip, *Masticophis flagellum*; California whipsnake, *Masticophis lateralis*; and common garter snake, *Thamnophis sirtalis*. The common garter snake, omitted from the park list, was observed during this study. The coachwhip was on the list, but its range is outside the park, and the California whipsnake requires chaparral habitat (Zeiner et al. 1988). The remaining species detected were those predicted as being in the habitats CWHR identified as suitable for reproduction.

The CWHR System predicted more species in both habitat types than were detected during sampling. In grassland, CWHR predicted the presence of 34 species: 19 mammals (excluding bats), 13 reptiles, and 2 amphibians. In coastal scrub, CWHR predicted 46 species: 27 mammals (excluding bats), 17 reptiles, and 2 amphibians. For the 2 habitats combined CWHR predicted 49 species: 29 mammals, 17 reptiles, and 3 amphibians. Our sampling detected 56% of the predicted grassland species and 54% of the predicted coastal scrub species.

Review of species notes for the 24 species that were predicted but not detected revealed that 11 could be eliminated because 1) they were at the limit of their range, 2) outside their range, 3) primarily used different habitats, or 4) required special habitat elements that were not available (Table 2). By excluding these 11 species, a revised CWHR prediction included 28 species reproducing in Marin County grassland (16 mammals, 10 reptiles, and 2 amphibians) and 36 species reproducing in Marin County coastal scrub (22 mammals, 13 reptiles, and 1 amphibian). For the 2 habitats combined, CWHR predicted 38 species: 23 mammals, 13 reptiles, and 2 amphibians. Our sampling detected 64% of these predicted grassland species and 71% of predicted coastal scrub species. For the habitats combined, we detected 65% of the predicted species: 68% of the mammals, 62% of the reptiles, and 50% of the amphibians. The CWHR System recognized a total of 288 species of mammals (exclusive of bats), reptiles, and amphibians in California (Zeiner et al. 1988, 1990b).

The CWHR theoretically predicts absence rather than presence, as it is assumed that all 288 regularly occurring mammals, reptiles, and amphibians in California occur everywhere unless one can show that a specific habitat, location, or habitat element is not available. By including predictions of species absence in the assessment of model performance, observed accuracy of CWHR model predictions increased to 96% for both habitats. Cohen's (1960) Kappa values of 0.755 and 0.784 indicate the validity of this approach by reducing the error of the confusion matrix (Tables 3 and 4).

Table 1. Terrestrial vertebrate species observed during 1990-1991 inventory, Golden Gate National Recreation Area, California. [a] CWHR predicted in coastal scrub only (CWHR version 9-10-89).

	Detection Method		CWHR
AMPHIBIANS	Systematic	Incidental	Omission
Salamandridae			
California newt, *Taricha torosa*		+	
REPTILES			
Iguanidae			
Western fence lizard, *Sceloporus occidentalis*	+		
Scincidae			
Western skink, *Eumeces skiltonianus*	+		
Anguidae			
Southern alligator lizard, *Elgaria multicarinatus*	+		
Northern alligator lizard, *Elgaria coeruleus*	+		+
Colubridae			
Racer, *Coluber constrictor*		+	
Gopher snake, *Pituophis melanoleucus*		+	
Terrestrial garter snake, *Thamnophis elegans*		+	
Common garter snake, *Thamnophis sirtalis*[a]		+	
Viperidae			
Western rattlesnake, *Crotalus viridis*		+	
MAMMALS			
Marsupialia			
Opossum, *Didelphis virginiana*	+		
Insectivora			
Vagrant shrew, *Sorex vagrans*	+		
Lagomorpha			
Brush rabbit, *Sylvilagus bachmani*		+	
Black-tailed hare, *Lepus californicus*		+	
Rodentia			
Southern pocket gopher, *Thomomys bottae*	+		
Western harvest mouse, *Reithrodontomys megalotis*	+		
Deer mouse, *Peromyscus maniculatus*	+		
Dusky-footed wood rat, *Neotoma fuscipes*[a]	+		
Meadow vole, *Microtus californicus*	+		
Carnivora			
Domestic dog, *Canis familiaris*	+		+
Gray fox, *Urocyon cinereoargenteus*[a]	+		
Raccoon, *Procyon lotor* [a]	+		
Striped skunk, *Mephitis mephitis*[a]	+		
Spotted skunk, *Spilogale gracilis*	+		
Domestic cat, *Felis catus*	+		+
Bobcat, *Felis rufus*	+		
Artiodactyla			
Black-tailed deer, *Odocoileus hemionus*[a]		+	
Domestic pig, *Sus scrofa*		+	+

Table 2. Terrestrial vertebrate species predicted by California Wildlife Habitat Relationship (CWHR) System that were not observed (defined as a commission error) during the 1990-1991 inventory in Golden Gate National Recreation Area, California. [a]CWHR predicted in coastal scrub only.

	Reason for Commission Error
AMPHIBIANS	
Plethodontidae	
California slender salamander, *Batrachoseps attenuatus*	
Ranidae	
Bullfrog, *Rana catesbeiana*[a]	Element-pond missing
REPTILES	
Chelydridae	
Western pond turtle, *Clemmys marmorata*	Element-pond missing
Iguanidae	
Coast horned lizard, *Phrynosoma coronatum*	Limit of range
Colubridae	
Ringneck snake, *Diadophis punctatus*[a]	
Sharp-tailed snake, *Contia tenuis*[a]	
Common kingsnake, *Lampropeltis getulus*	
Night snake, *Hypsiglena torquata*	
Coachwhip, *Masticophis flagellum*	Outside range
California whipsnake, *Masticophis lateralus*[a]	Chaparral habitat preferred
MAMMALS	
Insectivora	
Ornate shrew, *Sorex ornatus*	
Trowbridge shrew, *Sorex trowbridgii*[a]	Forest habitat preferred
Broad-handed mole, *Scapanus latimanus*	
Lagomorpha	
Desert rabbit, *Sylvilagus audubonii*[a]	Outside range
Rodentia	
Mountain beaver, *Aplodonita rufa*[a]	Outside range
California ground squirrel, *Spermophilus beecheyi*	
Heermann kangaroo rat, *Dipodomys heermanni*	Outside range
Pinon mouse, *Peromyscus truei*	
House mouse, *Mus musculus*	
Carnivora	
Coyote, *Canis latrans*	Outside current range
Ring-tail, *Bassariscus astutus*[a]	
Long-tailed weasel, *Mustela frenata*	
Badger, *Taxidea taxus*	
Mountain lion, *Felis concolor*	Limit of range

DISCUSSION

As a general tool to guide the inventory of mammals, reptiles, and amphibians in coastal scrub and annual grassland along the central California coast, our assessment indicates that the CWHR System performed better than reported from other habitats. After correcting for species with a low expectation of presence or detectability, our

Table 3. Confusion matrix for number of amphibian, reptile, and mammal species detected in grassland, exclusive of 14 bat species, Golden Gate National Recreation Area, California. (Proportion correct = 0.9618, $\hat{k}$ = 0.755).

	CWHR Prediction		
Observed	Present	Absent	Total
Present	19	1	20
Absent	10	258	268
Total	29	259	288

Table 4. Confusion matrix for number of amphibian, reptile, and mammal species detected in coastal scrub, exclusive of 14 bat species, Golden Gate National Recreation Area, California. (Proportion correct = 0.9583, $\hat{k}$ = 0.784).

	CWHR Prediction		
Observed	Present	Absent	Total
Present	25	1	26
Absent	11	251	262
Total	36	252	288

survey detected 71% of the species predicted by the CWHR System in coastal scrub and 64% of predicted species in grassland. These values are higher than the 32% reported by Barrett et al.[9] (1991) for valley-foothill riparian habitat or the 52% reported by Block et al. (1994) for oak woodland. Raphael and Marcot (1986) found an overall error of 43% for species presence in Douglas-fir habitats. One omission error of a non-domestic animal was observed: the northern alligator lizard, *Elgaria coeruleus*, was not predicted by the CWHR database model, but was found during the surveys. Three other omissions were of domestic species having the potential to significantly impact wildlife communities. The domestic pig was added to CWHR in a 1990 revision. Because of the continued urbanization and suburbanization of California, inclusion of the domestic cat and the domestic dog would be of value in future revisions of CWHR.

Errors of commission (species predicted by CWHR but not observed) were large; 24 species were predicted but not observed. However, 11 species were excluded from that total by considering range and habitat element information in the CWHR species notes. Several factors contributed to the commission error, including 1) the short duration (40 d) of the sampling period; 2) restriction of sampling to the dry, summer season; 3) failure to filter out species that required habitat elements not found at the study plots in the original query of the CWHR database; and 4) low abundance and detectability of some species.

Species composition predictions by the CWHR System can be refined by specifying seral stage and habitat elements. We did not screen, a priori, for these factors because we wanted to examine the broadest suite of resident species. We

[9] Barrett, R.H., B.T. Carre, E.B. Kleinfelter, and W.D. Tietje. 1991. Wildlife diversity in valley-foothill riparian habitat. California Department Forestry. Sacramento, California, USA.

assumed that a sample plot would detect an animal within its home range, although some species might exist at undetectably low abundance. Consequently, initial commission errors were higher than would be expected with a refined database search using habitat stages and elements. In this regard, the CWHR System offers a conservative approach by making biologists eliminate species from the list rather than take the chance of overlooking one.

The CWHR System is community based and theoretically predicts absence of species from a given habitat. Therefore, absences should be used to calculate CWHR accuracy. The observed accuracy increased to 96% for grassland and coastal scrub by adding the number of predicted absences. This approach may seem trivial, but is valid for the statewide level of specificity for which the CWHR database models are currently designed. By applying Cohen's (1960) method to assess agreement of classification categories, the CWHR model results had Kappa values of 0.755 for grassland and 0.784 for coastal scrub. These values mean that the error in predicting wildlife species was reduced by 76% and 78% compared to chance alone for grassland and coastal scrub, respectively.

Many field biologists are class or species specialists. The CWHR System provides the opportunity for a biologist to consider the array of biodiversity associated with habitats. This step is essential when devising inventory and monitoring projects to ensure that techniques are selected for the suite of species present rather than focusing on a class or a single species. The CWHR System, used properly, can guide wildlife biologists towards considering the full diversity of terrestrial vertebrates.

Although amphibians and reptiles were targeted in this study, our survey techniques were biased toward mammals. Artificial cover boards added several reptile species to the total, but the number of captures per unit effort was very small. Incidental observation added a number of species that would otherwise have gone undetected. Additional sampling at times when amphibians and reptiles are more likely to be detected would have increased the effectiveness of the inventory (Campbell and Christman 1982, Bury and Raphael 1983, Welsh[10] 1987, Corn and Bury[11] 1990, Heyer et al. 1994). However, as our study was a pilot program, only summer was sampled.

The CWHR requires continued validation efforts in all habitats. Studies like Block et al. (1994) are necessary for improving model performance, but it is critical to ensure repeatability in validation. Models are updated frequently and model version must be reported. Also, reporting actual predicted and observed species lists is required to evaluate model performance. Omission errors, once recognized and

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[10] Welsh. H.H. 1987. Monitoring herpetofauna in woodland habitats of northwestern California and southwestern Oregon: A comprehensive strategy. Pages 203-213 *in:* T.R. Plumb and N.H. Pilsbury, editors. Multiple-use management of California's hardwood resources. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, General Technical Report PSW-100. Berkeley, California, USA.

[11] Corn, P.S. and R.B. Bury. 1990. Sampling methods for terrestrial amphibians and reptiles. U.S. Department Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-256. Portland, Oregon, USA.

reported to the CWHR coordinator, should be corrected in the subsequent version of CWHR.

The future usefulness of the CWHR System requires 1) validation studies in all habitats for California, with results fed back to the CWHR database; 2) standardized field sampling protocols; 3) model refinement to incorporate multivariate species relationships with habitat; and 4) bioregionalization (e.g., Verner and Boss[12] 1980). Wildlife habitat relationships models are tools to guide our thinking and efficiency; they do not eliminate the need for empirical data and professional expertise when assessing a specific site or management action for impacts to wildlife.

ACKNOWLEDGMENTS

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[12] Verner, J. and A. Boss, technical coordinators. 1980. California wildlife and their habitats: Western Sierra Nevada. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, General Technical Report PSW-37. Berkeley, California, USA.

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EXPERIMENTAL ANALYSIS OF 3 INTERNAL MARKING METHODS FOR RED SEA URCHINS

PETER E. KALVASS and JON M. HENDRIX
California Department of Fish and Game
19160 South Harbor Drive
Fort Bragg, California 95437

PHILIP M. LAW
California Department of Fish and Game
411 Burgess Drive
Menlo Park, California 94025

Red sea urchin, *Strongylocentrotus franciscanus*, mark loss, mortality, and growth rates were compared among combinations of 3 marking methods: coded-wire tag (CWT), passive integrated transponder (PIT), and tetracycline (a chemical mark). Red sea urchins ranging in size from 12 to 89 mm test diameter were collected from the subtidal zone near Fort Bragg, California and held in a closed, recirculating seawater system for up to 205 days. Growth measurements were made at 93 and 205 days. Overall CWT loss rate was 17.6%; PIT loss was 10.0%. Mortality was 5.0%, with no significant difference among treatments. Growth, as measured by final test diameters adjusted for initial sizes by regression, was not significantly different among marking methods for the first 93-day period. For the entire 205-day period, adjusted mean test size differed significantly among marking methods. Mean test diameter growth ranged from 6.2 to 6.6 mm after 93 days and 8.0 to 11.5 mm after 205 days; 69% of the mean gonadosomatic index increase occurred by 93 days. Back-calculated growth rate of tetracycline-marked urchins after 205 days was 80% of their directly measured growth rate.

INTRODUCTION

A proven, simple external marking method, allowing for either unique identification or group marking of sea urchins, has yet to be devised. Existing external methods are cumbersome or short-lived, requiring drilling the test or elaborate wiring. *Centrostephanus coronatus* has been successfully marked with stainless steel wire threaded through holes created with hypodermic needles; however, the relatively thicker tests of strongylocentrotids make this method impractical (R.F. Ambrose, University of California, Los Angeles, personal communication.). We experimented previously with plastic anchor "T" tags, but urchins were able to pinch them off with their pedicellariae or shed them in some other manner within days. Non-toxic dyes have been tried for *Lytechinus pictus*, but they caused lesions or stressed the animals in other ways (J. Laughlin, King County, Washington, Environmental Laboratory, personal communication). In the same study, plastic spine collars were also tried, but urchins tended to shed the affected spines.

The genesis of our study was a desire to investigate the possibility of using coded-wire tags (CWTs) as a relatively inexpensive and efficient internal marking method for identifying individual red, *Strongylocentrotus franciscanus*, and purple, *S. purpuratus*, sea urchins in the field for studies of age, growth, and movement. It expanded to include another type of internal tag and a chemical marker.

The second type of internal tag, the passive integrated transponder (PIT) (Biosonics Corp.[1]), is relatively expensive (about $4.00–$5.50 per tag versus $0.05–$0.06 per unique sequential CWT [Northwest Marine Tech. Inc.[1]]), but reusable. Animals do not have to be sacrificed to be identified when using PIT tags, which allows interim growth measurements on the same animal, and PIT tags are much simpler to read than CWTs. Unique sequential CWTs are more complicated to work with and harder to read than batch-numbered CWTs. They require alternately tagging the urchin and the data sheet because the tag number is unknown at the time of tagging. With the added labor costs of the unique CWT, the PIT tag may be more cost-effective, especially in situations where the PIT tag is fully recoverable for reuse. One of our concerns, however, was whether the larger PIT tag size might affect growth and survival of urchins, particularly smaller individuals.

Chemical marks such as tetracycline and calcein have been used by sea urchin researchers in lieu of external tags (Ebert and Russell 1992, Schroeter and Dixon[2] 1993). Tetracycline is incorporated into calcium carbonate structures and fluoresces under ultraviolet illumination, marking the time of injection (initial size). The demi-pyramid (jaw) provides the most direct and least ambiguous growth measurement. The allometric relationship between jaw length and test diameter at the time of recapture (final size) allows back-calculation of initial test diameter from initial jaw length (Ebert and Russell 1992). We were interested in comparing growth rates calculated from direct measurement of initial and final sizes, made possible by the CWT, with indirectly measured growth rates from the tetracycline back-calculation method on the same urchins, as we were not aware of this comparison having been made. Tetracycline does not interfere with growth in *S. purpuratus* (Ebert 1988).

The primary objectives of our study were to 1) compare tag loss rates between PIT and CWT tags, 2) compare somatic and gonadal growth and mortality rates among 3 marking treatments, 3) examine urchin somatic and gonadal growth patterns over time, and 4) examine the tetracycline growth estimation method using urchins double-marked with CWTs and tetracycline.

METHODS

Red sea urchins ranging from 12 to 89 mm test diameter were collected in October 1995 from the Caspar Sea Urchin Closure Area about 8 km south of Fort Bragg,

[1] Reference to trade names does not imply endorsement by the California Department of Fish and Game.

[2] Schroeter, S.C. and J. Dixon. 1993. Estimating size-specific growth rates and population mortality rates for red sea urchins (*Strongylocentrotus franciscanus*) near Port Orford, Oregon. Ecometrics, 2270 Camino Vida Roble, Suite L, Carlsbad, California, USA.

California (39°21'N, 123°49'W). Previous field experiments have shown that large red sea urchins grow very slowly (Schroeter and Dixon[2] 1993, Ebert and Russell 1993), so urchins considerably smaller than the northern California commercial legal minimum size of 89 mm were selected in order to ensure measurable somatic growth during the experiment.

Red sea urchins were maintained at the Fort Bragg High School (FBHS) Marine Science Facility. The closed, recirculating system contained about 11,000 liters of sea water and three 1,300-liter square tanks were used to contain the marked red sea urchins (Fig. 1). Raw sea water was intermittently added to the system, which contained an in-line ultraviolet system and biological filter. In order to help maintain equivalent tank environments, tanks were connected in parallel to water inflow, which was circulated through a large mixing reservoir following recovery from the tanks.

We placed 159 CWT tagged red sea urchins in the 3 tanks in approximately equal numbers and equivalent size distributions (the distributions overlapped between 25 and 63 mm test diameter) (Table 1). In addition, all CWT-tagged sea urchins in Tank 1 were PIT tagged and all urchins in Tank 2 were tetracycline marked (Fig. 1). Water temperature in the facility varied from 11 to 18°C; the mean was 13.8°C. Red sea urchins were fed about every 2–3 days with brown algae, mostly *Nereocystis luetkeana*, to ensure that some food was always present in the tanks. Approximately 193 kg (wet weight) of algae was fed during the experiment, a mean of 110 g/individual/week.

All tags were injected into the body cavity via the peristomal membrane on the ventral side of the urchin. Each PIT tag is an 11-mm long by 2.1-mm diameter tubular glass capsule enclosing electronic components. CWTs are sequentially cut from 0.25-mm diameter stainless steel wire in sections 1.5–2 mm long. Tetracycline hydrochloride concentration was 1 g/100 ml sea water; 0.1–0.2 ml was injected per red sea urchin, depending on its size.

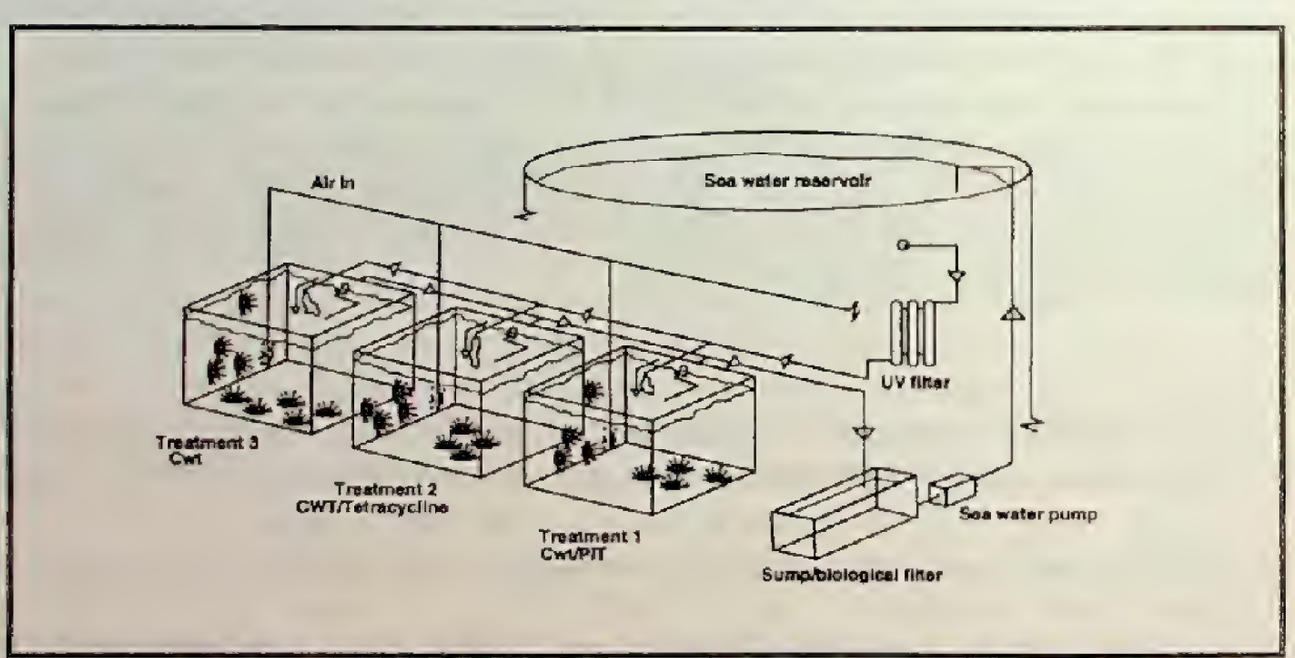

Figure 1. Fort Bragg High School closed recirculating sea water system showing tagging study design.

Table 1. Red sea urchin initial test diameter (mm) for PIT/CWT, tetracycline/CWT, and CWT-only treatments.

PIT/CWT			Tetracycline/CWT			CWT only		
N	Mean	SD	N	Mean	SD	N	Mean	SD
52	50.3	14.0	57	38.9	15.5	50	41.2	10.5

Initial red sea urchin test sizes, measured to the nearest millimeter using vernier calipers, were recorded on a data sheet and sequentially numbered CWTs were alternately affixed to the data sheet and injected into urchins, to allow linking of initial size data with each individual at the conclusion of the experiment. Test diameter measurements were replicated and the mean was used in calculations. Unique PIT tag numbers were recorded at the time of tagging for the PIT/CWT group.

A sample of red sea urchins of representative sizes from each treatment was processed at 93 days (31 January), the approximate experimental half-way point, for interim growth data. About 20 red sea urchins from the CWT-only and tetracycline/CWT groups were sacrificed for CWT recovery and identification, processing tetracycline-marked individuals for growth estimation, and recording growth measurements. We measured test diameter and height to the nearest millimeter using vernier calipers, and total weight and gonad weight to the nearest gram. The magnetized CWTs were detected by a magnetometer wand which audibly beeped when it was passed over a part of the urchin containing the tag. Using a binary-type search pattern in which successively smaller tag-containing pieces of the urchin were retained, CWTs were recovered relatively quickly. Tetracycline/CWT-marked red sea urchins were measured, Aristotle's lanterns were removed and cleaned in 5% sodium hypochlorite, and growth increments were measured on demi-pyramids (jaws) of the lantern. None of the PIT/CWT-marked red sea urchins were sacrificed in order to allow an additional measurement from each uniquely identifiable urchin at the termination of the experiment. At 205 days (23 May), all remaining individuals were sacrificed, tags extracted, and data recorded as above.

Mark loss, mortality rates, and growth rates were analyzed in several ways. Chi-square tests were used to examine mark loss and mortality rate differences among the marking treatments. A one-way analysis of covariance (ANCOVA) was used on log-transformed data to test for differences in growth increment among treatments; initial test diameter was the covariate in order to adjust for initial size differences among treatments. Monthly growth rate (G) was calculated as: $G = \ln(TD_{\Delta t}/TD_o)/(\Delta t/30)$, where TD = test diameter in millimeters and Δt = elapsed time in days. Test shape index (Rogers-Bennett et al. 1995) was calculated as the ratio of test height to test diameter and treatment effects were examined using ANCOVA, with initial test shape index as the covariate. Gonadosomatic index (GSI) was calculated as the ratio of gonad weight to drained whole body weight. Brody/Von Bertalanffy growth parameters, K and L_{inf} were estimated by linear regression of $TD_{\Delta t}$ on TD_o, $\Delta t = 205$ days (Ricker 1975). The final jaw length-test diameter allometric relationship was determined for red sea urchins double marked with tetracycline and CWTs after

each time period using linear regression (Ebert and Russell 1993). Results of the analyses were used to estimate test diameters at the time of marking. Monthly growth rates were calculated as before, using estimated initial test diameters for comparison with growth computed using directly measured initial test diameters.

RESULTS

Mark Loss and Mortality

Tag loss and mortality rate differed little among treatments. Overall CWT loss rate (17.6%) was not significantly different among tanks ($\chi^2 = 4.98$, df = 2, $P = 0.08$). Loss rate of the larger, more invasive PIT tag (10.0%) was lower, but not significantly different, than CWT loss rate (16.7%) in the PIT/CWT treatment ($\chi^2 = 0.76$, df = 1, $P = 0.38$). Total mortality was 5.0% (8 of 159 urchins died, 3 in the first 2 weeks of the experiment); mortality rates were not significantly different among treatments ($\chi^2 = 1.93$, df = 2, $P = 0.38$) (Table 2).

Growth Comparisons

The effect of marking treatment on growth varied with length of the experiment. Analyses of covariance on log-transformed data detected no significant differences among treatments for adjusted mean test diameters or regression slopes after 93 days ($P > 0.05$). However, adjusted mean test diameters ($P = 0.02$) and regression slopes ($P = 0.04$) were significantly different among treatments after 205 days (Table 3). Mean growth increments ranged from 6.2 to 6.6 mm among treatments for the 93-day group, with a projected annual growth rate of 24.9 mm. For the 205-day group, mean increments ranged from 8.0 to 11.5 mm, a projected annual growth rate of 17.1 mm. In both cases, the linear extrapolation to a full year is made with caution. As with growth increments, monthly growth rates (G) for each treatment were lower in the second growth period (205 days) than in the first period (93 days) (Fig. 2).

In PIT-tagged red sea urchins, a much higher proportion of growth occurred in the first 93 days for individuals >50 mm test diameter compared to smaller animals (Fig. 3). Growth commonly varied widely for animals of similar initial size and in the same treatment (tank). For example, of two 48.5-mm red sea urchins, one grew 10 mm in the first 93 days, while the other showed negative growth (Fig. 3).

Mean test shape indices for all treatments combined varied from 0.496 at day 0 (n = 150) to 0.483 at day 93 (n = 61) and 0.438 at day 205 (n = 86). Shape index decreased at the same rate for all 3 treatments over the course of the experiment ($F = 0.733$; df = 2, 77; $P > 0.05$). However, adjusted means were significantly different, ranging from 0.449 for the PIT/CWT treatment to 0.425 for the tetracycline/CWT treatment ($F = 11.51$; df = 2, 79; $P = 0.01$). Test shape was not correlated with test diameter ($r = 0.125$, n = 150, $P = 0.13$).

Data from all treatments were combined in order to estimate growth parameters. For red sea urchins 15–89 mm test diameter, estimated annualized Brody/Von Bertalanffy growth coefficient (K) was 0.35 and L_{inf} was 99 mm ($r^2 = 0.94$, n = 83) (Fig. 4).

Table 2. Chi-square tests of CWT loss and mortality rates among PIT/CWT, tetracycline/CWT, and CWT-only treatments.

	PIT/CWT	Tetracycline/CWT	CWT-only	Total
CWT loss				
N	30*	53	48	131
Tags Lost	5	11	7	23
% Lost	16.7	20.8	14.6	17.6
	$\chi^2 = 4.98$, df=2, P=0.08			
Mortality				
N	52	57	50	159
Mortalities	2	4	2	8
% Mortality	3.9	7.0	4.0	5.0
	$\chi^2 = 1.93$, df=2, P=0.38			

* Twenty additional red sea urchins in this group were not checked for tag loss.

Table 3. ANCOVA on log-transformed final red sea urchin test diameters with initial size as the covariate. Groups are PIT/CWT, tetracycline/CWT, and CWT-only for 0–93 days and 0–205 days.

0 to 93 days		Difference among adjusted means			
Source	df	SS	MS	F	P
Adj. means	2	0.0006	0.0003	0.0725	0.07
Error	60	0.2278	0.0038		
		Difference among slopes			
Among slopes	2	0.0034	0.0017	0.4458	0.45
Sum grp.dev.	58	0.2244	0.0039		
0 to 205 days		Difference among adjusted means			
Adj. means	2	0.0211	0.0106	3.8607	0.02
Error	82	0.2244	0.0027		
		Difference among slopes			
Among slopes	2	0.0175	0.0087	3.3732	0.04
Sum grp.dev.	80	0.207	0.0026		

Size-specific GSIs at 93 days and 205 days were similar (Fig. 5a); 69% of mean GSI increase occurred by 93 days (Fig. 5b).

Tetracycline Estimation Versus Direct Measurement of Growth

Although the relationship between final jaw length and test diameter was strong ($r^2 = 0.98$ for both 93-day and 205-day data), when applied to tetracycline-marked red sea urchins, it overestimated initial test diameters. Directly measured and estimated initial test diameters were significantly different for both time periods (93 days: $t = -5.63$, df = 15, $P < 0.005$; 205 days: $t = -3.54$, df = 17, $P < 0.005$).

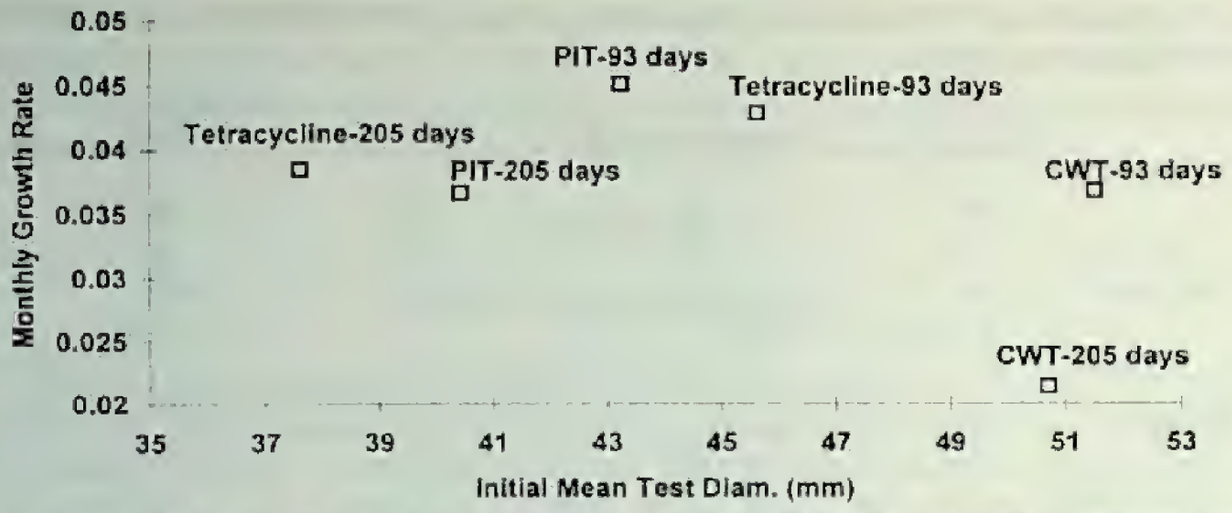

Figure 2. Monthly growth rate comparisons among tetracycline/CWT, PIT/CWT, and CWT-only treatments for 2 time periods: 93 days and 205 days.

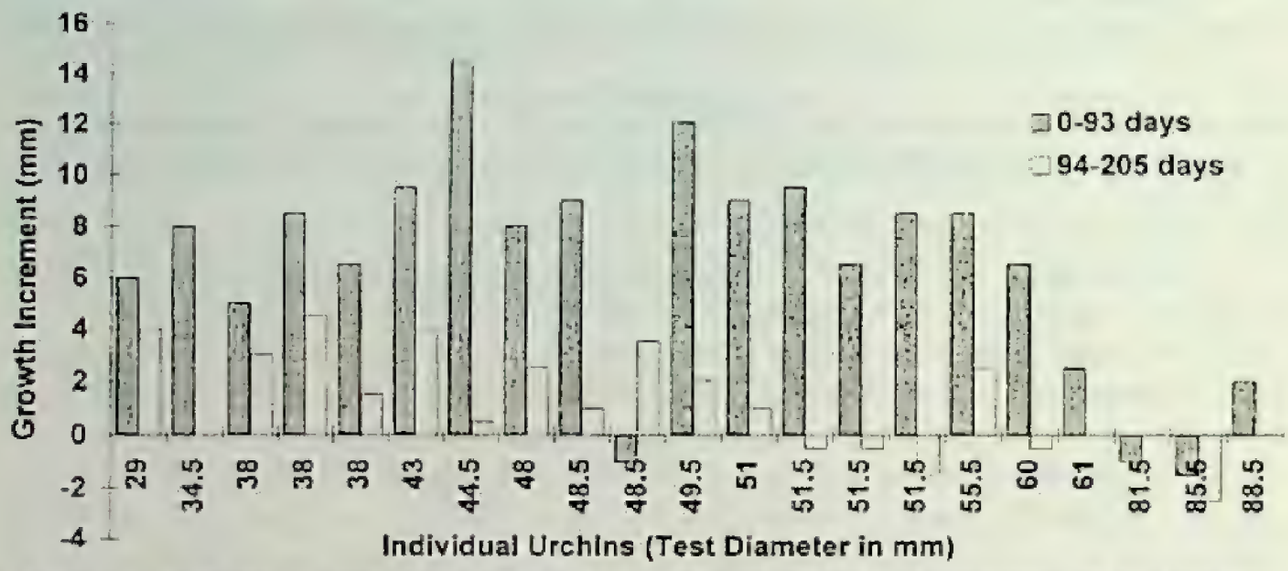

Figure 3. Size-specific growth increments of 21 PIT-tagged red sea urchins measured successively at 93 and 205 days. Mean initial size = 52.2 mm, mean 0- to 93-day growth = 6.5 mm, mean 94- to 205-day growth = 1.2 mm.

However, differences between estimated and measured initial test diameters were not significant for red sea urchins <40 mm (93 days: $t = -1.35$, $df = 5$, $P = 0.12$; 205 days: $t = -1.75$, $df = 9$, $P = 0.06$) (Fig. 6). Overestimation of initial test diameter resulted in tetracycline-estimated growth rate that was only 43% of that calculated by direct measurement at 93 days (0.017 vs 0.041). By 205 days, the difference had narrowed to 80% (0.031 vs 0.039).

Measurement error does not seem to explain the difference in growth rates obtained by the tetracycline method. Paired 2-sample t-tests on replicate measurements were not significant ($P > 0.05$) for either initial or final test diameter measurements for all urchins and for urchins grouped larger and smaller than 40 mm, except for the post-93-day group larger than 40 mm ($P = 0.03$).

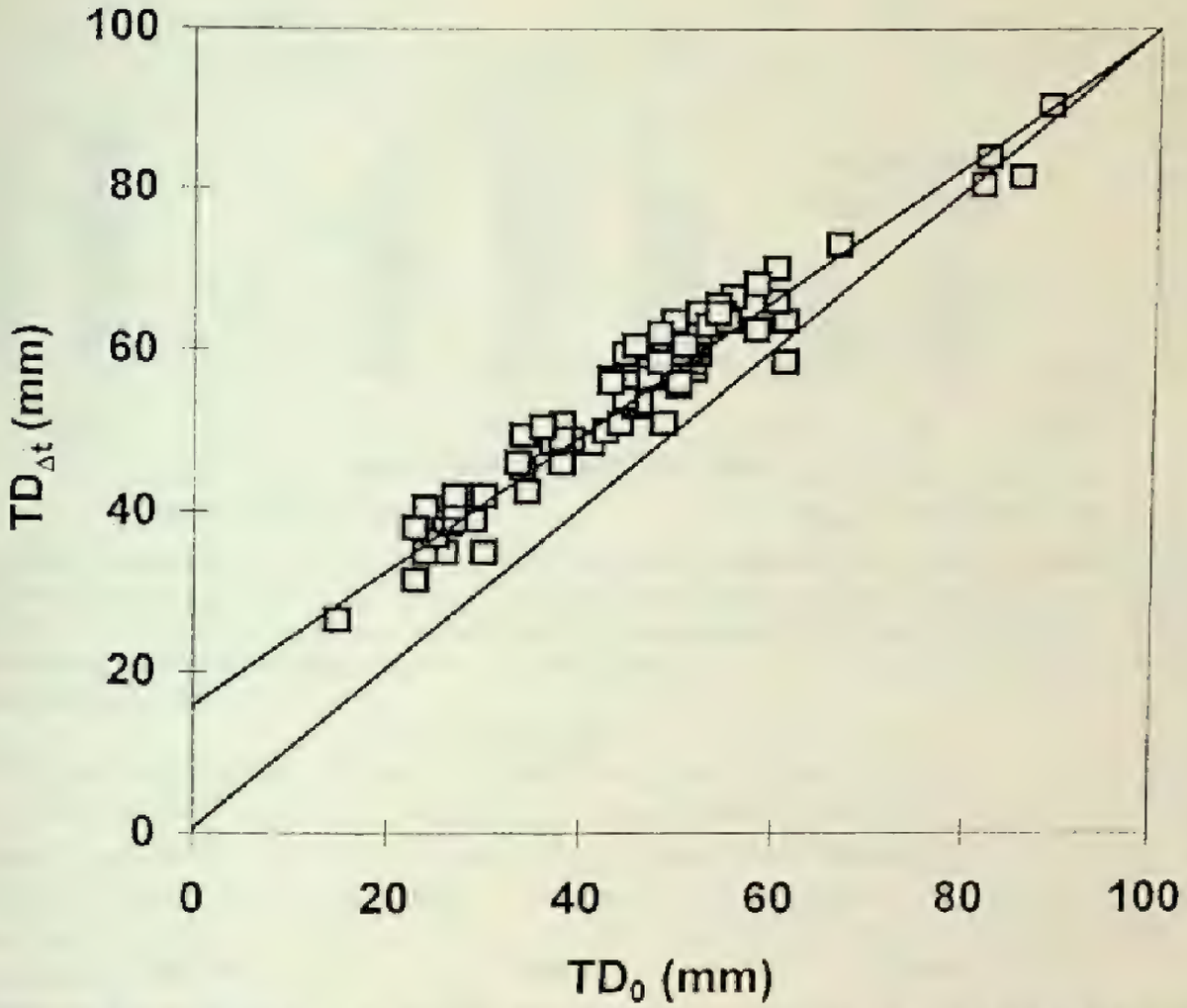

Figure 4. Linear regression of red sea urchin $TD_{\Delta t}$ on TD_0: $TD_{\Delta t} = 0.824TD_0 + 17.45$, $r^2 = 0.94$, $n = 83$, $\Delta t = 205$ days. Growth parameters: annual $K = 0.35$, $L_{INF} = 99$ mm.

DISCUSSION

Growth Comparisons

Differences in growth rates among treatments were probably not biologically important, as the maximum difference between adjusted mean test diameters was only 2 mm. Differences for the 93-day period were not statistically significant and significance for the entire 205-day experiment was low. Also, sample size (n = 84) for the 205-day period was higher than the 93-day period (n = 62); hence, the ANCOVA for the 205-day period has greater power to reject a false null hypothesis (Table 3). However, potential interaction between mark types (i.e., the presence of one mark mitigates the effect of the other mark) confounds the results. Because of this, we can only tentatively conclude that the effects of a PIT tag alone or a tetracycline mark alone would not differ from the effect of a CWT alone. Although Ebert's (1988) study showing the benign effects of tetracycline on purple sea urchin growth supports our conclusion, future work should include unmarked urchins as a control.

The high growth variability that we observed in this laboratory experiment has also been reported for urchins in field studies (Schroeter and Dixon[2] 1993,

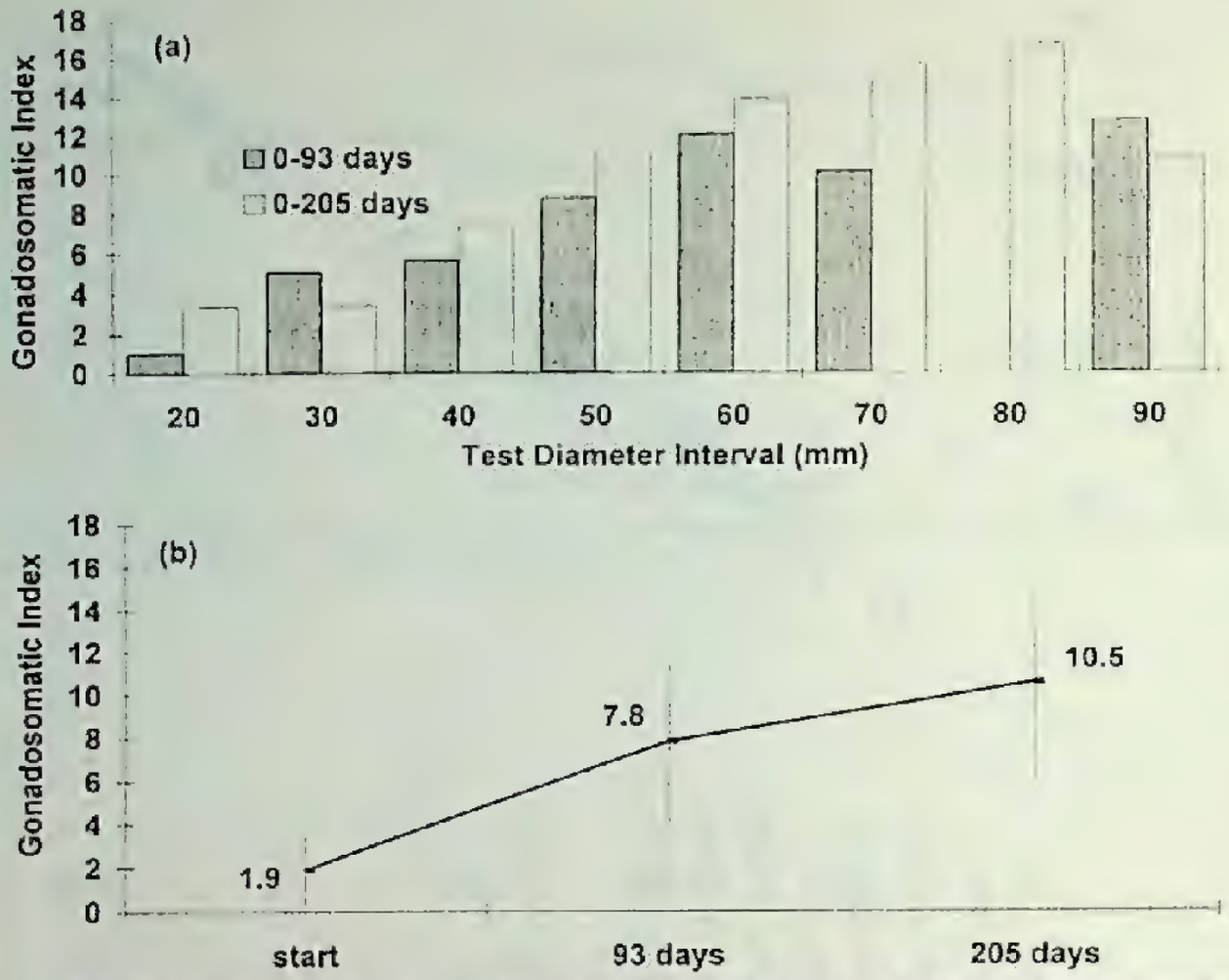

Figure 5. Red sea urchin size-specific gonadosomatic indices (GSI) (a) and mean GSI over time (b). Vertical bar = SD.

Rogers-Bennett et al.[3] 1994). Some of this variability may be due to measurement error, but actual test shrinkage has been associated with starvation (Ebert 1967). As our red sea urchins were adequately fed, zero or negative growth in our study would not seem to be due to lack of food.

Test shape in sea urchins may be environmentally mediated. In some cases, conspecific urchins from exposed habitats (i.e., shallower depths) exhibit lower shape indices than urchins from protected (deep) habitats. This flatter profile is less subject to the effects of turbulence (Marcus 1983, in Rogers-Bennett et al. 1995). Although our adjusted mean test shape indices differed among treatments, mean test shape indices for a depth-segregated population of red sea urchins near Bodega Bay, California varied over a range (0.472–0.449) similar to ours and were not considered different (Rogers-Bennett et al. 1995).

The Brody/Von Bertalanffy growth coefficient (K) estimated for our captive red sea urchins (0.35) was substantially higher than K estimated for tetracycline-marked red sea urchins at San Nicolas Island in southern California (0.093) (Ebert and Russell

[3] Rogers-Bennett, L., H.C. Fastenau, T. Hibbard-Robbins, Z. Kain, and C.M. DeWees. 1994. Culturing red sea urchins for experimental outplanting in northern California. Final Report of the Director's Sea Urchin Advisory Committee, Contract FG-2230-MR, July 18, 1994. California Department of Fish and Game, Sacramento, California, USA.

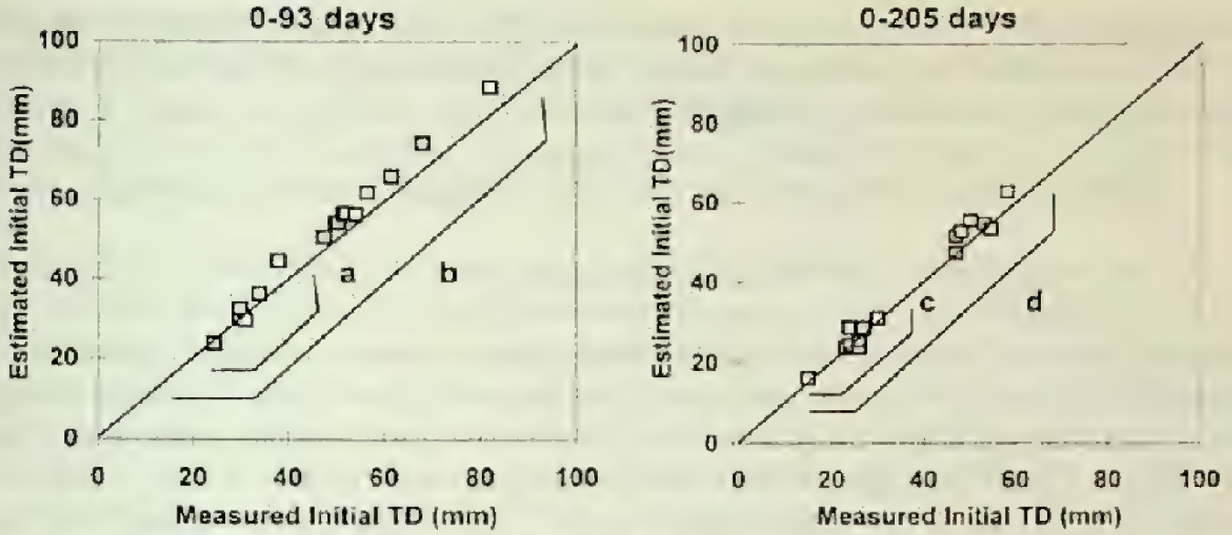

Figure 6. Estimated versus directly measured initial test diameter (TD) for tetracycline/CWT-tagged red sea urchins at 93 and 205 days. Paired t-tests were not significant for groups (a) and (c) ($P = 0.12$, $P = 0.06$), but were significant for groups (b) and (d) ($P < 0.005$ for both). Monthly growth rate 0 to 93 days: estimated = 0.017, measured = 0.041; 0 to 205 days: estimated = 0.031, measured = 0.039.

1992), but slightly lower than in a laboratory study (0.48) (Botsford et al. 1993). A larger K means a more rapid decrease in the difference between L_t and L_{inf}. It also means a smaller L_{inf} and slower growth from that time onward (Ricker 1975). The small K of the San Nicolas Island urchins is not unexpected as they were larger than our urchins (i.e., closer to L_{inf}) and grew in a more food-limited natural environment for 1 year.

Our red sea urchins may still have been keyed into their seasonal gonadal maturation cycle, as a high proportion of their gonad growth occurred by 31 January and, in the field, some of the highest gonad yields of the year occur in January and February (Kato and Schroeter 1985). Gonadosomatic indices for our largest red sea urchins were comparable to the highest annual levels of 12–14% found in catch samples from northern California (Kalvass and Hendrix 1997). High GSIs are correlated with the period prior to gametogenesis and the onset of spawning (Pearse et al. 1986).

Sea urchin growth and reproduction respond to such exogenous factors as changing day length, but the response varies among species. In purple sea urchins, somatic and gonadal growth compete with gametogenic activity for available energy and these processes are under photoperiodic control (Pearse et al. 1986). Gonadal and somatic growth are highest in summer and fall, times characterized by longer day length; hence, manipulation of photoperiod can influence resource allocation between growth and gametogenesis (Pearse et al. 1986). Results of our study and other research suggest that, unlike purple sea urchins, gonad size peaks in red sea urchins during the winter months in northern California (Kalvass and Hendrix 1997).

Variation in water temperature between 11 and 18°C during our study probably did not affect gonad growth. Red sea urchins fed an excess of either *N. luetkeana* or an artificial diet under two temperature regimes (16.1 and 12.9°C) showed no significant difference in GSI after 120 days (McBride et al. 1997). Although water

temperature has been shown to affect gonad growth in southern populations of purple sea urchins, no correlation has been found between temperature and gonad growth in northern populations (Bay-Schmith and Pearse 1987).

Tetracycline Estimation Versus Direct Measurement of Growth

The accuracy of the allometric relationship between jaw length and test diameter may be responsible for the discrepancy between tetracycline-estimated and directly measured growth. The relationship may have changed in our field-collected urchins in response to the sudden abundance of food available in the lab, or it may not be valid to calculate the relationship over the limited size range of urchins we studied. The implication of these findings for field studies using the tetracycline growth estimation method is that growth increments for urchins larger than about 40 mm may be underestimated. Further research should be undertaken in representative sea urchin habitats using double marks with tetracycline and CWTs or tetracycline and PIT tags.

Practical Considerations

Processing efficiency varied greatly among the 3 mark types. Coded-wire tags, with their double-tagging requirement and tag recovery, tag cleaning, tag reading, and linking of the in vivo tag with its data sheet companion, averaged approximately 20 minutes per tag. Processing of tetracycline marks is an involved, multi-stage process that takes about as long as CWT processing. Reading and extracting the larger PIT tag was much faster, on the order of a few minutes per tag.

The development of a PIT tag reader and a CWT detector for use underwater would greatly improve field utility for these tag types. Processing times for CWTs and tetracycline marks vary with the experience of the readers. Cost comparisons should take into account the relative cost of marking and processing equipment; tetracycline marking and processing materials are much less expensive than the specialized PIT tag reader and CWT injector and detectors. Depending on project objectives, and whether individual sea urchins need to be identified for multiple measurements over the course of an experiment, 1 mark type may be more appropriate than the others. The PIT tag has high utility for cases where small numbers of animals are to be marked and movement of animals is expected to be limited to allow for reasonable tag recovery rates. PIT tags have been successfully used in the field for sea urchin age and growth study with at-liberty times of up to 1 year (L. Morgan, University of California, Bodega Marine Laboratory, personal communication).

ACKNOWLEDGMENTS

We thank the California Department of Fish and Game Director's Sea Urchin Advisory Committee for providing funds and labor for the FBHS Marine Science Facility and for funding J. Hendrix. Also, we thank FBHS student S. Ross and his instructor F. Rubin, who were instrumental in the conception and execution of this experiment. S.C. Schroeter of Ecometrics assisted in the experimental design and

graciously provided for the examination and measurement of the urchin jaws. S. McBride of California Sea Grant and L. Rogers-Bennett aided in experimental design. J. Geibel and F. Henry assisted with statistical analysis and manuscript review. Finally, we received invaluable assistance from P. Wright, C. Talbot, P. Burton, and R. Everett.

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OCCURRENCE OF XANTHIC GRASS ROCKFISH, *SEBASTES RASTRELLIGER*

DAVID CRIPE
Monterey Bay Aquarium
886 Cannery Row
Monterey, California 93940

Xanthic coloration has been reported in several families of fishes (Dawson 1964, 1966, 1971; Dawson and Heal 1976). In the Scorpaenidae, it has been observed in 5 species in the genus *Sebastes*, but this is the 1st record of xanthic coloration in the grass rockfish, *S. rastrelliger*. Phillips (1957) reported the occurrence of golden bocaccio, *S. paucispinis*; golden vermilion rockfish, *S. miniatus*; and golden widow rockfish, *S. entomelas*, from Monterey Bay, California. Other reports of golden rockfish include a bocaccio from British Columbia (Davenport 1966) and a xanthic China rockfish, *S. nebulosus*, off Crescent City, California (Ueber 1989). Okihiro et al. (1993) observed xanthophore pigment associated with skin lesions in yellowtail rockfish, *S. flavidus*, from Cordell Bank, off central California.

In 1993 and 1996, 2 xanthic grass rockfish were landed off the central California coast by commercial fisherman D. Allan. The 1st of these was caught by hook and line on 3 August 1993 at a depth of 7 m near the mouth of Alder Creek on the Big Sur coast (35°51'N, 121°24'W). Grass rockfish are typically dark green with lighter green and brown mottling (Miller and Lea 1972). This grass rockfish was not completely orange; the coloration consisted of a bright orange background with a greenish-black mottling on the dorsum.

The 2nd xanthic rockfish was landed with hook and line on 12 October 1996. This specimen was caught at a depth of 7 m just west of Pescadaro Point in Carmel Bay, California (36°34'N, 121°57'W). It was donated to the Monterey Bay Aquarium and is currently on exhibit. Initially, this specimen's entire body was bright orange, but over the 12 months following capture, the color faded to a lighter yellow-orange and some olive-green mottling appeared on the head and dorsum. The fading of the orange color may be due to a diet low in prey items containing high levels of carotenoid pigments.

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IN MEMORIAM

RICHARD S. CROKER (1907–1998)

Richard S. Croker died on 3 January 1998 at the age of 90 in Laguna Nigel, California. Dick (as he was known to his many friends and colleagues) was a fisheries scientist, conservationist, environmentalist (before the term became popular), administrator, international diplomat, and former president of the American Fisheries Society (1961–1962).

His career covered 6 decades and included state, interstate, national, international, military, and private sector service. After graduation from Stanford University in 1929, he began his career as a fisheries biologist serving as a railroad fish car attendant husbanding the delivery of fish eggs and fry from California fish hatcheries throughout the state. Over the years he progressed through the ranks of state service to become Senior Marine Biologist in the Marine Fisheries Branch at the California State Fisheries Laboratory at Terminal Island. There he developed his biological skills, wrote many publications, and was appointed editor for Department of Fish and Game publications, ensuring the quality of the Department's quarterly scientific journal and the fish bulletin series. He assisted in the preparation of professional quality manuscripts for many colleagues before submission to other journals.

From 1942 to 1946, he served in the Air Force with final duty as Fisheries Officer in Japan with General Douglas MacArthur's occupation military forces following World War II. He assisted the government of Japan in the redevelopment of its fisheries sector and made many friends in the Japanese fisheries community. After discharge, he returned to the Department of Fish and Game, where he was appointed Chief of the Marine Fisheries Branch, later to become the Marine Resources Branch. Dick retired from the Department to become the Executive Director of the Pacific Marine Fisheries Commission for 1962–1963. His professional and international skills were rewarded by a 5-year appointment as Regional Fisheries Officer for Latin America for the U.S. Department of State with headquarters based in the U.S. Embassy in Mexico City. In this position, he was responsible for the fisheries and wildlife sectors covering diplomatic and technical duties throughout the region.

Following his tour of duty with the State Department, Dick was retained as a consultant to the Administrator of the United Nations Development Programme (UNDP) to review and advise on U.N. projects in over 10 countries, where he often had to exert firm diplomacy in order to accomplish his assignments. Dick was a tall and imposing figure and, with his affable but strong demeanor and voice, could often accomplish in a personal visit to a project what written communications could not. Interspersed with assignments to the UNDP, he served as consultant to individual foreign governments, the International Service Corps, and the Resources Development Associates.

Throughout his life, besides being a professional fisheries scientist, he was also an ardent amateur fisherman. He kept detailed scientific records of his fishing and

catches. He often professed chagrin at being bested by his constant fishing companion and first wife, Annie, expressing, with tongue-in-cheek concern, that his reputation as a fisheries official might be diminished were it to become widely known that Annie could catch more fish than he.

Richard S. Croker was a prolific correspondent, writing in a left-handed classic script of observations of his travels, activities, feelings, and fishing successes, always with humor and accuracy. He authored numerous articles and papers on fisheries and wrote hundreds of reports, reviews, and comments on the technical matters of his consultancies.

He was a member or former member of the American Fisheries Society, American Society of Ichthyologists and Herpetologists, American Institute of Fishery Research Biologists, Gulf and Caribbean Fisheries Institute, Pacific Marine Fisheries Biologists, Sierra Club, and Nature Conservancy.

All his life Dick gave a superb measure of enthusiasm to all that he engaged in and was a scientist of distinction, a statesman, and a genial colleague. He was the devoted father of Kenneth Croker and Cathy Dolbear. He is survived by his widow Arlene Croker of Laguna Nigel, California.

– *Wm. Ellis Ripley*
221 Hacienda Place
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